The effects of stocking density on heavy turkey tom productivity, health, and wellbeing to 16 weeks of age

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Overall Abstract

The impacts of increasing stocking density (SD) were observed on Nicholas Select turkey toms (n=2,868) to 16 wk of age. In two trials, birds were allocated to 8 independently controlled rooms (6.7x10.0 m = 67.5 m^2) based on final predicted body weight, resulting in a total of 4 room replicates per treatment. Air quality was monitored via carbon dioxide and ammonia and was equalized across treatments. The number of birds placed differed by density to reach a final predicted density (based on Aviagen, 2015a Performance Objectives) of 30, 40, 50, and 60 kg/m^2. Productivity was evaluated using body weight and feed consumption at 0, 4, 8, 12, and 16 wk of age, and feed efficiency was calculated at 4 wk intervals. A brief economic analysis was conducted based on productivity. At 12 and 16 wk of age, a sample of 20 birds per replicate were weighed for determination of flock uniformity, feather condition and cleanliness, footpad lesions, and mobility. The heterophil/lymphocyte ratio (H/L) was evaluated at 4, 12, and 16 wk (15 birds per replicate) and core body temperature was evaluated at 16 wk (3 birds per replicate). Behavioural expression was analyzed at 12, 14, and 16 wk using a scan sampling technique. Data were analyzed using regression analyses (Proc Reg for linear and Proc RSReg for quadratic relationships; SAS®9.4). Differences were significant when $P \leq 0.05$, and trends were noted when $P \leq 0.10$. Overall body weight and body weight gain decreased linearly as SD increased. Feed consumption decreased linearly as SD increased within the last 4 wk (12-16). Mortality corrected feed-to-gain ratio demonstrated an increasing linear relationship with SD beginning at 4 wk and continuing throughout the trial. Body weight uniformity and total percentage mortality and culls showed no impact in relation to increasing SD. Footpad lesion severity and frequency and bird mobility were negatively impacted in relation to increasing SD. Feather condition and cleanliness decreased linearly with increasing SD over the course of the trial. The H/L ratio demonstrated an increasing linear relationship with increasing SD at 4 wk of age. Core body temperature increased with increasing SD. Behaviour was altered in relation to increasing density with increases in comfort behaviours, decreases in nutritive behaviours, and quadratic effects on mobility behaviours. The economic analysis, based on production parameters alone, supported increased monetary return with increasing SD. High levels of SD negatively impact bird performance, health and wellbeing, although the economic return continues to improve with increasing density.

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ACTH	**adrenocorticotropic hormone**
d	**day**
F:G	**feed-to-gain**
F:G^m	**mortality corrected feed-to-gain**
GS	**gait score**
H/L	**heterophil/lymphocyte ratio**
HPA	**hypothalamic-pituitary-adrenal axis**
SD	**stocking density**
wk	**week**

1.0 Chapter 1. Literature review: the effects of stocking density on the performance, health, and behaviour of broiler chickens and turkeys

1.1 Introduction

In 2016, the Canadian turkey industry was comprised of 551 farms responsible for the production of 183.3 million kg of turkey products (Turkey Farmers of Canada, 2016). Although it is a relatively small industry in comparison to the chicken industry, which is comprised of over 2,800 producers (Chicken Farmers of Canada, 2017), the turkey industry is focused on addressing areas of priority to both consumers and producers including bird health and welfare, food safety, and sustainability (Turkey Farmers of Canada, 2015). Due to the smaller size of the industry as well as species differences and handling difficulties, research involving turkeys is limited as compared to broiler chickens. As a result, the majority of literature concerning turkeys was published in the 1980-1990s. While this research undoubtedly has given us important information regarding turkey production, the target market body weight has changed dramatically. Heavy toms are grown to significantly heavier weights with a steep growth curve. For example, a study reported in 1969 recorded an average body weight of 4.32 kg for male turkeys at 14 wk of age, compared to the most recent commercial objectives set out by Aviagen of 13.60 kg for a 14 wk male turkey (Coleman and Leighton, 1969; Aviagen, 2015a). That alone may indicate there is a need for increased knowledge in the areas of current turkey production practices and the effects on welfare and production.

In commercial poultry production, stocking density (SD) has been seen as one of the primary drivers for economic return. It is also an area of concern when evaluating animal welfare. While production variables are simple to measure, welfare is not. Three main aspects are important to consider when assessing welfare. These include natural living, affective states, and biological functioning (Fraser et al., 1997). Therefore, to obtain a comprehensive understanding of the effects of varying SD, it is important to understand the effects on bird performance, health, stress, and behaviour in order to ensure the bird's welfare needs are being met as well as ensuring the industry is profitable. Stocking density has been assessed in depth for broiler chicken production, with extensive data demonstrating the effects of increasing SD on growth, mortality, stress, and behaviour (Proudfoot et al., 1979a; Martrenchar et al., 1997; Thaxton et al., 2006; Estevez, 2007).

In comparison to broiler SD research, there is much less information regarding the effect that varying SD has on turkey broilers or heavy turkey toms. There are also few studies which have incorporated all three of the following aspects: production, health, and behaviour. In addition, the majority of these studies evaluating turkey production were published in the early 1990's or earlier. That being said, past studies have utilised many parameters in evaluating the effects of SD on turkeys including bird performance, foot pad lesions, lameness, feather condition, behaviour, and others (Coleman and Leighton, 1969; Proudfoot et al., 1979b; Noll et al., 1991; Martrenchar et al., 1999). It is important to note that the impact of SD on these parameters has not been consistent across studies, which could be due to other contributing factors such as densities tested, environmental conditions, or gender differences (Denbow et al., 1984; Zuidhof et al., 1993; Martrenchar et al., 1999). In order to get a more accurate prediction of the effects of SD, it is important to eliminate or reduce some of these confounding factors.

In addition to confounding factors, another challenge related to assessing the effects of SD is that differing methodologies have been used to achieve the density differences. For example, group size can be altered while floor space is maintained (Moran, 1985; Noll et al., 1991; Martrenchar et al., 1999), while other research studies have altered the pen size while bird numbers are constant (Coleman and Leighton, 1969; Denbow et al., 1984; Buchwalder and Huber-Eicher, 2004). In commercial settings a change in group size is likely more easily applied compared to changing rearing facilities. It is also difficult to compare previous studies as they are not consistent in their description of space allowance. Some studies indicate space allowance as the amount of floor space allocated per bird (Coleman and Leighton, 1969; Martrenchar et al., 1999), whereas other studies indicate the total body weight per unit of space (Zuidhof et al., 1993; Dozier et al., 2005). To allow comparison between studies included in this thesis, studied space allowances have been converted to kilograms per square meter (kg/m^2) when possible using reported body weights.

Since there is minimal research involving turkey SD, the objective of this research is to contribute knowledge of the effects of SD on turkey productivity, health, and welfare. A secondary objective of this research is to provide data to assist in creating recommendations for producers regarding housing density of heavy turkey toms.

1.2 Techniques for Evaluating Bird Welfare

Evaluating welfare in birds can be quite difficult as it is challenging to get an accurate representation of the bird's affective state. Multiple parameters must be used in combination to assist in making inferences to what the bird is experiencing. One parameter that can be used to evaluate the affective state of a bird is stress. Often, techniques that we use to evaluate stress can be influenced by the method of collection and the handling of the bird and therefore are not true representations of the stressors being evaluated (Le Maho et al., 1992). Physiological parameters such as heart rate, respiratory rate, and glucocorticoid concentration, can be used in combination as indicators of acute stress. In the event of a stressor, the central nervous system responds to the stimuli by rapid catecholamine release, resulting in increasing blood pressure, respiration rate, and increases in blood glucose concentration. The endocrine system is also triggered by the stimuli, resulting in the activation of the hypothalamic-pituitary-adrenal (HPA) axis and glucocorticoid release via adrenocorticotropic hormone (ACTH). As a result, corticosterone, the primary glucocorticoid secreted in birds, concentrations increase rapidly in the blood (Siegel, 1980). While measuring corticosterone from a blood sample may be a better indicator of circulating levels of hormone in relation to an acute stressor, corticosterone is metabolized relatively quickly and metabolites can be measured in the excreta of birds. Excreta metabolites can be collected without disturbing or handling the birds, minimizing the effects of handling stress (Wasser et al., 2000). Corticosterone also plays a role as an inhibitor of HPA axis function, as a result it may alter the stress response under chronic stress conditions (Dallman et al., 1992). For this reason, as well as its rapid release and breakdown, corticosterone may not be a suitable parameter to evaluate long term stressors such as SD, but better suited for the evaluation of short term stress (Gross and Siegel, 1983).

For longer periods of stress, another less invasive method of measuring corticosterone concentration may be useful. The concentration of corticosterone may be measured in feathers, as it is deposited slowly via the feather follicle. As a result the feathers may be able to represent the body’s corticosterone concentration over a longer period of time when related to feather growth (Bortolotti et al., 2008). The production of corticosterone acts to negatively impact the production of corticotropin-releasing factor (Vandenborne et al., 2005) resulting in reduced circulating concentrations. As a result, other methods of measuring long-term stress may be more applicable. Some of the other methods of evaluating longer periods of stress may evaluate the effects of the stress response on physiological changes to the body, including shifts in immune status and function. This is primarily due to a shift in metabolism, as a result of circulating hormones, where the bird’s energy expenditures are directed toward the stress response and away from maintenance and production status. These shifts in circulating hormone concentration and metabolic status can result in changes in parameters such as the heterophil/lymphocyte (H/L) ratio and size of immune organs such as the bursa, thymus, and spleen. As birds become stressed, typically the number of heterophils increase and lymphocytes decrease resulting in a higher H/L ratio, suggesting that the bird is experiencing a constant negative state (Gross and Siegel, 1983; Huff et al., 2005). A study conducted by McFarlane and Curtis (1989) evaluated the effects of multiple stressful inputs on 10 d old chicks. Birds were stressed over a 7 d period via a combination of six stressors (ammonia concentration, beak trimming, coccidiosis exposure, electric shock, heat stress, and noise) and blood samples were collected on d 17. The authors found no effect of these particular stressors on plasma corticosterone, however the H/L ratio was significantly increased, especially when birds were exposed to multiple stressors. The authors concluded that likely the birds' corticosterone response occurred more rapidly and returned to baseline by d 7, however the H/L ratio may be a better indicator of chronic environmental stress. Another study conducted by Puvadolpirod and Thaxton (2000) evaluated the stress response in broilers continuously administered adrenocorticotropic hormone (ACTH) for 7 d at 6 wk of age. They found that the H/L ratio responded to ACTH infusion by d 2 and continued to show elevated levels when compared with the control until d 10. These findings support the previous findings that H/L ratios may be better suited for long term stressors.

Using behaviour in combination with physiological and physical parameters can be helpful in determining the impact of a stressor on bird wellbeing. Birds may cope with stressors through behavioural responses. Disruptions in the frequency or the pattern of behaviours such as comfort behaviours (preening, stretching, wing flapping, etc.) can often indicate that the birds are frustrated or stressed. Preening behaviour is important for feather maintenance and condition (Delius, 1988). Birds typically perform preening behaviour when they are comfortable; however it has also been associated with stress or frustration in the form of displacement behaviour. Duncan and Wood-Gush (1972) found that birds that were frustrated (due to restricted feed access in this particular work) performed shorter preening bouts and the majority of this time was focused on easy to access areas such as the neck, breast, and outer wing compared to hard to reach areas such as the back and under the wing. Alternatively, another study conducted in wild gulls suggested that preening could be a coping behaviour. The authors evaluated preening behaviour before and after a predator threat and found that birds were 31% more likely to preen following a threat from a predator, suggesting that preening may help them cope with stress (Henson et al., 2012). In addition to displacement behaviours, fear behaviours such as tonic immobility have also been used as an indicator of stressors in birds (Jones and Faure, 1981). Tonic immobility has been used to evaluate stressors as it is said to relate to the bird's fight or flight response. Campo et al. (2007) found that birds exposed to continuous light had an increased duration of tonic immobility and an increased H/L ratio. These findings suggest that tonic immobility is a useful measure for chronic stressors as birds also demonstrated physiological effects of stress. Another study evaluating the effects of long day length demonstrated no effect on duration of tonic immobility (Schwean-Lardner et al., 2012). These results suggest that there are many variable factors that may impact the reliability of tonic immobility as a stress measure, therefore it is important to consider multiple parameters. Tonic immobility has not been frequently used in domestic turkeys as they often do not respond in a similar manner to chickens. Noble et al. (1996) suggested that there was a relationship between body weight and duration of tonic immobility, with heavier bird lines taking longer to right themselves.

Another physical trait that may affect bird mobility, health, and welfare is footpad lesions. The pain associated with footpad lesions can alter the bird's ability to walk (Weber Wyneken et al., 2015). The causes of footpad lesions are multifactorial however they can be associated with the environment the bird is housed in (Mayne, 2005). Another key factor related to footpad lesions is their relationship to bird health as they may act as an infection route for secondary infections (Martrenchar et al., 2002). Feather condition and cleanliness may also relate to bird health and welfare. These are both important for several reasons, including thermoregulation, feed efficiency, protection from scratches, and proper hygiene in order to minimize risks of pathogens (Leeson and Morrison, 1978; Davami et al., 1987; Forkman and Keeling, 2009). Feather pecking, or the removal of feathers from pen mates has been suggested to be associated with increased stress (El-Lethey et al., 2000). In addition, feather removal via pecking by a pen mate has been shown to be painful (Gentle and Hunter, 1990), and the removal of feathers may result in open wounds encouraging cannibalism (Forkman and Keeling, 2009).

In addition to measuring parameters directly associated with the bird, there are stressors present in the environment such as poor air quality and high litter moisture. Air quality parameters such as CO_2, ammonia, particulate matter, humidity, and infectious organisms can be measured and certain levels may present health risks to the bird (Zuidhof et al., 1993). Poor air quality such as high ammonia levels can lead to many health issues associated with the respiratory tract as well as damage to the eyes and mucous membranes (Ritz et al., 2004). In broilers, increases in litter moisture and ammonia have been linked to dirty foot pads, poor leg scores (angulation), more birds showing visible hock lesions, and high excreta corticosterone concentrations (Dawkins et al., 2004).

In summary, there are many ways stress can be evaluated, however it is important to select stress measures that are a good indicator of the type of stress you expect to see (for example chronic vs. acute). It is also important to utilize multiple parameters to ensure that a well-rounded assessment of the type of stressor the animal is experiencing is being accurately tested. Finally, multiple parameters may work together to demonstrate adverse effects due to a stressor which may be missed by only evaluating a single parameter.

1.3 Broiler Stocking Density

The effects of SD on broiler chickens have been well studied, with the majority showing overall decreases in performance, no effect on mortality, decreases in mobility, increases in stress responses, and changes in overall behaviour. Recommended SD is variable across organizations and countries; the current recommendation for Canadian producers is 31 to 48 kg/m^2 depending specific environmental conditions and required management practices being met as outlined in the Canadian Codes of Practices (NFACC, 2016). In addition to measuring the effects of SD on typical performance objectives, health parameters, and behavioural observation, other novel studies have also examined the effects of SD on tonic immobility, corticosteroid metabolites, and fluctuating asymmetry, overall providing results to assist in establishing commercial recommendations.

1.3.1 Productivity

Broiler performance effects in relation to SD have been well documented, as they have direct effects on economic gain. The most common parameters used to evaluate bird performance have been body weight and feed efficiency. Even though today's broilers have a more rapid growth curve, earlier studies conducted with more slow growing birds still show decreases in final body weight as SD increases (Heishman et al., 1952). Proudfoot et al. (1979a) found similar linear decreases in performance when male and female broilers were reared in equal numbers at four densities ranging from 3.72 to 9.27 dm^2/bird [49.3 to 22.3 kg/m^2] up to 51 d of age, however, there was no effect on feed conversion. Similarly, when straight-run broilers were housed at 0.05, 0.07, 0.09, and 0.11 m^2/bird [37.9, 28.0, 22.7, and 18.5 kg/m^2] up to 35 d of age, there was a decrease in body weight for birds housed at the highest density when compared to all other treatments (Cravener et al., 1992). Another study examined male and female broilers reared to 41 d of age at two final densities: 27.35 and 43 kg/m^2 (Martrenchar et al., 1997). The authors found that birds housed at higher densities were significantly lighter, with males demonstrating a larger difference in body weight than females. More recent studies have also demonstrated decreases in body weight associated with increasing densities up to 38 kg/m^2 at 35 d of age (Dozier et al., 2006). Along with a decrease in body weight, an increase in the feed-to-gain ratio, from 1.535 to 1.580, was observed when SD increased from 25 to 38 kg/m^2 at 35 d of age. The authors noted that feeder and drinker space were within recommendations for commercial practice as outlined by Lacy (2002), however space per bird was not consistent across treatments. Conversely, Buijs et al. (2009) reported no effect on body weight in broilers raised to 39 d of age at final densities from 6 to 56 kg/m^2. In a large scale commercial study, Dawkins et al. (2004) examined commercial flocks with five target SD (30, 34, 38, 42, and 46 kg/m^2) with a total of 2.7 million birds. They found that there were linear decreases in bird growth rate as SD increased, however they did not see an effect of density on mortality or the incidence of poor mobility. Another performance parameter that is often evaluated for broilers is the coefficient of variation for body weight as it relates to carcass uniformity and is important not only for processing but for reaching specific markets. Feddes et al. (2002) examined the effect of four SD ranging from 11.9 to 23.8 birds/m^2 [22.79 to 45.17 kg/m^2] and found that at the lowest SD there was greater variability in body weight compared to birds housed at the three higher densities.

Mortality is an economically important parameter, especially in older birds as the producer has more expenses invested. Mortality numbers are equally important for bird welfare as we want to ensure that birds are not experiencing unnecessary pain and suffering. Mortality in an early trial did not differ as SD increased (Proudfoot et al., 1979a). A study conducted by Bilgili and Hess (1995) quantified mortality of both male and female broilers at three time periods and three densities 0.07, 0.08, and 0.09 m^2/bird for males and 0.06, 0.07, and 0.08

m^2/bird for females [29.2-35.2 kg/m^2 for males; 22.6-30.7 kg/m^2 for females]. They found significantly higher mortality in male broilers raised at higher densities in the starter period (1-21 d) with a similar but not significant pattern seen in the withdrawal period (42-49 d). Female broilers followed the same numerical pattern, with higher mortality at higher densities, although this was also not statistically significant. In a later study by Dozier et al. (2006), mortality was not affected by increasing SD up to 38 kg/m^2 up to 35 d of age. Buijs et al. (2009) also reported no effects on mortality in relation to increasing SD from 6 to 56 kg/m^2.

Carcass quality is another economically important parameter that has been well studied in relation to broiler SD. The incidence of downgrading due to breast blisters has been shown to increase linearly as SD increases in female broilers and the same numerical but not significant pattern was seen in male broilers (Proudfoot et al., 1979a). Bilgili and Hess (1995) evaluated the effects of density on carcass traits, including scratches and bruising, on both male and female broilers, reared at densities ranging from 0.07-0.09 m^2/bird [29.2-35.2 kg/m^2] and 0.06-0.08 m^2/bird [22.6-30.7 kg/m^2]. The authors noted that male broilers demonstrated an increase in thigh lesions with increasing density, however the increase was not high enough to impact grading level at processing. Male broilers also demonstrated an increase in breast fillet weight as a percentage of live weight at lower densities corresponding to the increase in overall body weight observed. Female broilers demonstrated an increase in lesions overall, with the total of sores/scabs and scratches being the highest in birds reared at the highest density. Dozier et al. (2006) found that as SD increased from 25 to 38 kg/m^2 carcass weight decreased. However there were no significant effects on carcass fat yield, tears, or scratches.

An economic analysis performed by Proudfoot et al. (1979a) included feed cost, chick cost, and revenue based on kilograms live weight. Though these prices have obviously changed, the authors found that return per unit of floor space increased as SD increased. The authors did not consider the effects of carcass downgrading, which may have influenced monetary gains. The study conducted by Cravener et al. (1992) included an economic analysis on profit potential and included variables such as meat price, feed cost, feed intake, grower payment, kilograms of downgraded carcass per square meter, and cost of downgrade per kilogram. Their analysis included three different approaches, two of which supported the findings of Proudfoot et al. (1979a) where profit potential increased as SD increased. Interestingly, when they used a more conservative method with lower values for meat and feed price, the intermediate SD 0.07m^2/bird [28.0 kg/m^2] resulted in the greatest profit potential (Cravener et al., 1992). Both Proudfoot et al. (1979a) and Cravener et al. (1992) emphasized the importance of distinguishing profit per bird and profit per unit of space as they will greatly influence the interpretation.

1.3.2 Bird Health and Physical Condition

The effects of SD on broiler health have been evaluated using parameters such as foot pad lesions, gait score, feather cover, stress physiology parameters and immune response. Stocking density is thought to be a stressor for many reasons. Environmental stressors associated with increasing SD may include increased litter moisture as well as poor air quality in relation to increased bird numbers. Social stressors associated with increasing SD may include increased competition for access to resources (Bilčík et al., 1998; Martrenchar et al., 1999), difficulty establishing a social hierarchy (Keeling et al., 2003), or increased difficulty performing natural behaviours because of space limitations (Hall, 2001). These stressors can contribute to an overall stress response in the bird and potentially result in decreased immune function. There are many physiological parameters that can be measured to attempt to quantify the stress response in birds, however heterophil to lymphocyte ratio (H/L ratio) has been cited as being one of the most accurate methods for evaluating chronic stressors when compared to corticosterone concentration (Gross and Siegel, 1983).

Thaxton et al. (2006) examined the effects of SD on five stress parameters including the concentration of plasma corticosterone, plasma glucose, plasma cholesterol, H/L ratio, and total nitrites (as measures of the adaptive stress response and oxidative stress). Blood samples were taken from broilers housed at densities ranging from 30 to 45 kg/m^2 at 49 d. Stocking density had no effect on plasma corticosterone, plasma glucose, plasma cholesterol, and total nitrite concentration, however the H/L ratio increased linearly as SD increased (Thaxton et al., 2006). A more recent study also observed a significant increase in the H/L ratio associated with increasing density from 6 to 13 birds/m^2 [14.5 to 28.7 kg/m^2] (Simitzis et al., 2012). There are also conflicting results when evaluating H/L ratios. Contrary to the findings of Thaxton et al. (2006) and Simitzis et al. (2012), Martrenchar et al. (1997) examined the effects of three SD: 12, 16, and 20 birds/m^2 [27, 35, and 43 kg/m^2] on the H/L ratios of mixed sex broilers at 41 d and found no significant differences. They concluded that it was not possible to determine whether this was due to SD not being a stressor, or if the H/L ratio was a poor predictor of chronic stress due to SD. In a more recent study, the reliability of H/L ratios was evaluated (Lentfer et al., 2015). The authors suggested that although the H/L ratio may suggest a physiological change due to a stressor, there is a large amount of individual variation making comparison to a reference value difficult; therefore it is likely more practical to pair H/L ratios with other measures of stress such as behavioural changes or other health indicators.

Other less common methods have also been used to evaluate stress and immune function. Buijs et al. (2009) used corticosteroid metabolites in the excreta as an alternative measurement of stress in relation to SD, however there were no significant differences across treatments. This is as expected because corticosterone secretion is often a result of acute stressors and returns to baseline when evaluated in terms of chronic or long term environmental stressors such as SD (McFarlane and Curtis, 1989). Another method used to evaluate immune function may be to evaluate bursa size. However, increasing SD showed no effect on absolute bursa weight or the bursa to body weight ratio, when evaluated in 39 d broilers housed at SD ranging from 6 to 56 kg/m^2 (Buijs et al., 2009). Simitzis et al. (2012) also evaluated the effects of SD on bursa weight and found decreased bursa weight at higher densities.

Stress can also be influenced by the environment, increasing SD has also been shown to increase litter moisture (Martrenchar et al., 1997; Sørensen et al., 2000), in turn increasing the incidence of foot pad lesions (Dozier et al., 2005). Other environmental conditions such as temperature and humidity may also be influenced by SD and litter moisture, which may contribute to the overall air quality that the birds are subjected to (Martland, 1984; Martrenchar et al., 1997). Dozier et al. (2006) found that increasing SD resulted in increased litter moisture, ranging from 29.6 to 43.3% moisture at densities of 25 and 38 kg/m^2, respectively. The study also found that foot pad lesion scores (scale: 0=no lesion, 1=<5mm lesion, 2=>5mm lesion) increased from 0.375 to 1.238 as SD increased. Litter moisture and ammonia are closely linked to bird health as well as they are directly associated with a higher incidence of dirty footpads and prevalence of hock lesions (Dawkins et al., 2004). This has been shown in several studies where authors noted an increase in foot pad lesions as well as hock burns associated with increasing bird densities (Sørensen et al., 2000; Buijs et al., 2009). Sørensen et al. (2000) also noted that there was a positive correlation between the incidence of hock burns and body weight and the incidence of hock burns and walking ability.

Gait score (GS) can also be used as a tool to evaluate the wellbeing of the bird for a number of reasons, including the relationship to the birds' ability to move comfortably to feed and water. Sørensen et al. (2000) conducted two trials evaluating the effects of SD on broiler GS at two ages, 35 and 49 d of age, and varying densities ranging from 455 to 625 cm^2/bird [24 to 32 kg/m^2] and 435 to 833 cm^2/bird [34 to 61 kg/m^2] for each age, respectively. Both trials found that increasing SD was associated with poorer gait scores, with a higher portion of birds scoring higher (for poor mobility) as birds aged. Other studies have used alternative methods of evaluating leg health, such as the latency to lie test, which measures the amount of time a bird remains standing in a water bath (Buijs et al., 2009). When using the latency to lie test, the authors observed a decrease in leg strength or willingness to stand as SD increased.

Locomotive ability can also be impacted by bone strength and development. Buijs et al. (2012) evaluated the effects of increasing SD ranging from 2.4 to 21.8 birds/m^2 [6 to 56 kg/m^2] on broiler leg health. Increasing SD resulted in decreased tibia strength and increased tibia curvature, which may be a contributor to lameness (Buijs et al., 2012). They also evaluated fluctuating asymmetry of the tibia as an indication of the coping ability of the bird, with increasing asymmetry indicating decreased bird welfare. In this case, the authors reported a tendency for increased asymmetry with increasing density was observed (Buijs et al., 2012). Other studies have also evaluated fluctuating asymmetry of the tibia in relation to SD, with conflicting results. At densities of 8, 13, and 18 birds/m^2 [21, 34, and 47 kg/m^2] there were no differences observed in the relative fluctuating asymmetry across treatments (Ventura et al., 2010). Conversely, Møller et al. (1995) observed increases in fluctuating asymmetry as SD increased from 20 to 28 birds/m^2 [body weight not reported].

Feather condition and cleanliness scoring can be used as a tool to evaluate the overall health of the bird, however feather condition is important also for protection of the bird from scratches which impact both bird welfare and meat quality. Poor feathering has been shown to affect feed efficiency, which may be used as a measure of bird performance and health (Leeson and Morrison, 1978). Proudfoot et al. (1979a) observed that birds at high densities (3.72 dm^2 [49.3 kg/m^2]) appeared, in the authors definition, more rough and tattered compared to those housed at lower densities (9.27 dm^2 [22.3 kg/m^2]), however these data were not analyzed statistically. Thomas et al. (2004) evaluated feather cover on the breast area on a scale of 1-3, with 1=no visible skin, 2= small amount of skin showing, and 3=large amount of skin showing. They found that increasing densities from 9.64 to 35.79 kg/m^2 resulted in poorer breast feather scores, which is likely attributed to increased contact with wet litter.

1.3.3 Behaviour

Locomotion and resting behaviours may be impacted by increasing SD as space becomes more limited as birds grow. Martrenchar et al. (1997) examined the resting behaviour of mixed sex broilers housed at three densities ranging from 12, 16, and 20 $birds/m^2$ [27, 35, and 43 kg/m^2]. They found that resting birds were disturbed most often at the highest density compared to the other two densities, however the total duration of the lying bout (measured in seconds) was not affected by density. They also concluded that the level of activity decreased as SD increased. Hall (2001) also observed a decrease in walking activity (number of steps taken) and incidence of ground pecking at higher densities when birds were housed up to 40 kg/m^2 compared with 34 kg/m^2. Buijs et al. (2010) also examined bird behaviour in relation to SD. Broilers were housed at 7 densities ranging from 6 to 56 kg/m^2 and behaviour was evaluated from 2-6 wk of age, one day per wk at 6 time points where focal birds were observed for 5 minute intervals. The authors reported that higher densities resulted in shorter sitting and preening bouts and an increase in disturbances described as a bird adjusting their sitting or lying posture without fully standing up. In addition to behavioural observation, they also evaluated spatial distribution of the birds (daily from 4-6 wk), monitoring the number of birds in four locations: inner, inner middle, outer middle, and outer portions of the pen. At four wk of age, there were few significant differences with a higher proportion of birds found in the inner portion of the pen at 35 kg/m^2. At 5 wk of age, there was a higher portion of birds found in the outer portion of the pen at 47 kg/m^2. Finally, at 6 wk of age, birds housed in all five treatments with density greater than 33 kg/m^2 showed significant differences with density being consistently higher in the outer portion of the pen. The authors suggested that at higher densities the birds are more likely to seek out a location to minimize the number of disturbances by pen mates. They also stated that temperature and humidity are not likely the cause as they were within normal ranges and were measured at bird height over the course of the trial (Buijs et al., 2010).

Other behaviours that may be impacted by increasing SD include: feeding and drinking behaviour and fear related behaviour. The probability of a bird standing at the feeder was significantly lower when birds were housed at higher densities such as 13 birds/m^2 [28.7 kg/m^2] compared to lower densities 6 birds/m^2 [14.5 kg/m^2] (Simitzis et al., 2012). Similar data were noted in this study for time spent at the drinker. The authors mentioned that walking ability also decreased as SD increased and suggested that at higher densities there was a greater amount of interference between birds especially around feeders and drinkers. As a result birds may position themselves further from these areas to avoid disturbances. Fear can be difficult to evaluate, however tonic immobility has been commonly used as it relates to the bird's reactivity when exposed to a stressful situation. A study was performed using mixed sex broilers at several densities ranging from 6 to 56 kg/m^2. The authors found a tendency (P=0.08) for increasing density to increase fearfulness (Buijs et al., 2009).

1.4 Turkey Stocking Density

Studies evaluating the effects of SD on turkeys have shown overall decreases in performance, increased lameness and foot pad lesions, as well as changes in behaviour; however there has not been a significant response in mortality due to differing densities in the reported literature. Current industry recommendations vary widely; the Canadian Codes of Practice currently recommend a range of densities from 40 to 65 kg/m^2 dependent on bird age and final target body weight as well as other environmental and management conditions that producers must meet to house birds at the higher SD recommendations (NFACC, 2016).

1.4.1 Productivity

Typical traits used to evaluate productivity include body weight, feed efficiency, flock uniformity, morbidity and mortality (Zuidhof et al., 1993). Previous studies have also included carcass quality as a measure of productivity (Coleman and Leighton, 1969; Proudfoot et al., 1979b). Coleman and Leighton (1969) evaluated the effects of floor space on both tom and hen performance, with five space allowances ranging from 6.5 to 12.1 square decimeters per bird (dm^2/bird) [36.6 to 62.6 kg/m^2 per tom and 27.5 to 48.0 kg/m^2 per hen] up to 14 wk of age. Body weight was negatively affected by decreased space allowance at 14 wk of age, but not at 10 wk of age, demonstrating that SD became increasingly important as the birds aged. Males demonstrated a greater response to decreasing SD in relation to unit of space per bird, as they were larger at 14 wk of age and likely experienced more stressors due to space restrictions. These authors also found no effect of space allowance on feed efficiency. Proudfoot et al. (1979b) evaluated the effects of floor space on both males and females up to 14 wk of age. Three densities of males ranging from 11.1 to 18.8 dm^2/bird [32.0 to 50.8 kg/m^2] and three densities of females ranging from 7.4 to 14.7 dm^2/bird [30.4 to 55.1 kg/m^2] were included in this study. Significant reductions in body weight were seen with increasing SD levels, and once again, there was no effect on feed efficiency. The conclusions drawn from both of these studies were that increasing SD results in poorer weight gain, but that it does not impact feed efficiency.

Contrary to the findings of Coleman and Leighton (1969) and Proudfoot et al. (1979b), Denbow et al. (1984) and Noll et al. (1991) found SD effects on both body weight and feed efficiency at high levels of SD. The study by Denbow et al. (1984) examined turkey toms in three separate time periods 0-8, 8-12, and 12-20 wk of age. Three densities were tested from 0-8 wk, ranging from 6.5 to 12.1 dm^2/bird [19.6 to 35.5 kg/m^2], and body weight was not impacted. Three densities were tested from 8-12 wk ranging from 11.7 to 21.8 dm^2/bird [25.5 to 43.9 kg/m^2]. In this section of the experiment, body weight was significantly lower in the higher SD treatments. At the last time period, 12-20 wk, birds were housed in two different housing systems: the brooder house with floor space allowance at 11.7, 16.7, and 21.8 dm^2/bird [51.7, 67.3, and 92.7 kg/m^2] and the grower house with floor space at 28.0, 35.0, and 42.0 dm^2/bird [26.8, 31.4, and 39.8 kg/m^2]. The birds housed in the brooder space did not differ in body weight when housed at the two lower densities, but were smaller at the highest density. Birds housed in the grower space showed no significant differences in body weight. The authors also noted an effect on feed efficiency from 8-12 wk with birds in higher SD demonstrating poorer feed efficiency. This was also noted at 12-20 wk with birds at the highest SD performing poorer than those at a lower SD. Noll et al. (1991) demonstrated similar results in toms up to 20 wk of age where birds were housed at two final densities, 0.21 and 0.46 m^2/bird [29.4 and 60.9 kg/m^2]. They noted that after wk 12, birds in the higher SD demonstrated poorer growth. Feed efficiency was reduced in the last four weeks (16-20 wk) for birds in the high SD treatment.

Martrenchar et al. (1999) evaluated body weight in turkey hens up to 12 wk of age and turkey toms up to 16 wk of age, however they did not evaluate feed efficiency. Hen SD ranged from 10 to 16 dm^2/bird [38.8 to 62.7 kg/m^2] and tom SD ranged from 25 to 40 dm^2/bird [33.5 to

52.3 kg/m^2]. The authors noted that in both hens and toms, body weight was significantly lower in the higher SD treatments. From this and previous described literature, it is well established that SD has a significant effect on body weight of turkeys as they age, although it is still unclear of its effect on feed efficiency.

Carcass lesions such as breast blisters, breast buttons, and scratches are a concern from both a bird health, welfare and an economic standpoint. In Canada, turkey carcasses are graded as Canada A, Canada Utility, and Canada C, and may be downgraded due to the presence of defects such as blisters, scratches, skin tears, and discolouration (CFIA, 2014). Therefore, these lesions are not only painful for the bird and result in an increased opportunity for infections/mortality but represent an economic loss to the producer. Coleman and Leighton (1969) observed a numerical decrease in the percentage of birds grading "A" in the high SD treatment (6.5 dm^2/bird [62.6 kg/m^2]) as compared to the low density treatment (12.1 dm^2/bird [27.5 kg/m^2]). Proudfoot et al. (1979b) found similar results with a higher percentage of birds being downgraded as SD increased from 18.81 to 11.10 dm^2/bird [32.0 to 50.8 kg/m^2]. A study conducted by Moran (1985), found that there was a greater number of carcasses that were graded "utility" under high SD [24.7 kg/m^2] at 18 wk of age when compared to the low SD treatment [12.7 kg/m^2]. Martrenchar et al. (1999) saw an increased incidence of scratches and scabs on the hip region in turkey toms housed at higher densities, which would result in downgrading at the plant. Aside from carcass quality, Halvorson et al. (1991) suggested that SD may also play a role in carcass composition as the percentage of abdominal fat increased at lower densities (29.5 kg/m^2) compared to high SD (70.0 kg/m^2) in turkey toms raised until 20 wk of age. Absolute breast meat yield may also be affected by SD, however this is likely due to the increased body weight at low SD (Halvorson et al., 1991).

The impact of SD on turkey mortality has not been clearly identified. Coleman and Leighton (1969) found that mortality was only numerically (but not statistically) higher in males housed at high SD ([62.6 kg/m^2] no *P*-value reported). In another study, a tendency was noted ($P<0.06$) for higher mortality with high SD [60.9 kg/m^2] compared to low SD [29.4 kg/m^2] (Noll et al., 1991).

1.4.2 Bird Health and Physical Condition

Foot pad lesions are strongly viewed as a welfare concern as they have been shown to cause pain and affect bird mobility (Weber Wyneken et al., 2015). It has been suggested that the incidence of foot pad lesions is positively related to litter moisture (Martland, 1984), which may be related to increasing bird density. Martrenchar et al. (1999) saw a tendency for litter dry matter to decrease as SD increased ([33.5 to 52.3 kg/m^2] P=0.1), the authors also noted that ventilation was managed separately for each room. The increase in SD has also been shown to increase the incidence of foot pad lesions when birds were raised at three densities ranging from 12 to 40 dm^2/bird [33.5 to 52.3 kg/m^2] to 16 wk of age (Martrenchar et al., 1999). The incidence of foot pad lesions may also be associated with poor gait scores (as a measure of mobility), which is indicative of pain (Martrenchar et al., 1999; Weber Wyneken et al., 2015).

Mobility is an area of concern when evaluating SD as it has been suggested that higher SD restricts the ability of the birds to exercise, resulting in a decrease in overall activity. This reduction in activity may contribute to the bird's ability to maintain proper leg function (Classen et al., 1994). Martrenchar et al. (1999) examined the effects of SD on mobility of both turkey toms and turkey hens using a subjective gait score procedure. Turkey hens experienced poorer mobility at higher SD at 12 wk of age. Turkey toms also demonstrated deleterious effects on gait score when housed at high SD up to 16 wk of age.

Feather cover may be important in terms of live market quality and risks for meat quality, as well as poor quality may be detrimental to bird wellbeing. Lack of feathering may result in a higher incidence of lesions prior to slaughter. These lesions are not only painful but may result in down grading at the processing plant (McEwen and Barbut, 1992). Incidence of breast buttons has also been associated with poor feather cover, likely due to the increased contact with the litter (Newberry, 1993). Feather cover also affects feed efficiency as feathers help to maintain body temperature (Leeson and Morrison, 1978). Feather cover has not been typically evaluated when assessing turkey SD, however Coleman and Leighton (1969) observed a slightly poorer feather cover scored on a scale of 1-4 (scale: 1=uniform feathering over the body, 4=devoid of feathers) associated with high SD ([up to 62.6 kg/m^2] no P-value reported).

Another method used to evaluate bird health and immune status in relation to a stressor is the H/L ratio. Heterophil/lymphocyte ratios have not been used as frequently in turkey research in comparison to broiler chicken research. A study conducted by Hafez et al. (2015) studied the effects of SD (25, 48, and 58 kg/m^2) under commercial farm conditions on various health parameters. The authors found no significant differences in H/L ratios at 7, 12, 16, and 20 wk of age in relation to SD. Other studies evaluating stressors in turkeys have included the use of H/L ratios as a measure of the impact of stress. Huff et al. (2005) examined at the effects of transport stressors and disease challenge on the H/L ratio in three genetic lines of turkeys. The H/L ratios increased in both transport stressed birds and disease challenged birds in relation to the control, with the overall percentage of heterophils increasing and lymphocytes decreasing. Another transportation study evaluated the effects of hot transport conditions over 8 hours on 16 wk old turkey hens. The authors found that hot temperatures (35°C) resulted in an increase in the H/L ratio when compared to birds transported at a neutral temperature (20°C) (Vermette et al., 2017). The conflicting results between stressors such as SD and transport suggest that H/L ratios may be more sensitive to certain types or lengths of stress exposure.

1.4.3 Behaviour

Bird behaviour is an important parameter to evaluate when assessing the welfare conditions associated with high SD. Behaviour such as aggression has been shown to be associated with pen size, with more turkeys demonstrating more aggressive behaviours in smaller pens. This is likely due to a lack of adequate space for the target bird to retreat (Buchwalder and Huber-Eicher, 2004), emphasizing the importance of taking into consideration altering pen size as opposed to group size when evaluating SD. Alternatively, Denbow et al. (1984) saw no increase in aggressive behaviours relative to SD when birds were housed at densities ranging from 11.7 to 42.0 dm^2/bird [26.8 to 92.7 kg/m^2]. Another study evaluated the effects of density (2.5, 3.0, and 3.5 birds/m^2; body weight not reported) on turkey behaviour and found that feather pecking was higher with birds housed at low SD (Gunthner and Bessei, 2006). Other behaviours such as walking and time spent resting may be affected by SD, although there are few studies evaluating these parameters. Martrenchar et al. (1999) evaluated the behaviour of turkey hens up to 12 wk of age and turkey toms up to 16 wk of age. No change in walking activity (walking or running but not performing another categorized activity simultaneously) was noted as SD increased. There was no difference in the number of birds disturbed while resting at higher densities. The authors also found no effect of SD on either frequency or duration of feeding and drinking behaviour.

1.5 Conclusions

While many of the previous studies outline the effects of SD on bird productivity, health, and behaviour, few studies examine these traits together as a whole. It is also important to note that many of these studies do not account for air quality as well as other factors resulting in confounding effects with SD. A study conducted by Dawkins et al. (2004) evaluated five final predicted SD on ten commercial broiler farms (30, 34, 38, 42, or 46 kg/m^2). They evaluated bird parameters including production, behaviour, and health; they also included temperature, humidity, litter quality, and air quality. Overall, SD had minor effects on the productivity and welfare of the birds, and they concluded that environment played a large role in incidence of culls and mortality. Both litter moisture and ammonia levels significantly affected bird health, with temperature and humidity significantly linked to poor performance and mortality. The authors concluded that while SD has an effect on welfare of the birds, the environmental factors and management practices have a greater effect on bird health. This demonstrates the overall importance of minimizing the effects of environmental differences across treatments when evaluating SD.

1.6 Objectives

The primary objective of this research was to provide comprehensive data regarding the effects of stocking density on turkey toms, by assessing a wide range of variables including both performance and welfare parameters.

To accomplish this, several other objectives were included:

- To determine the effects of SD on turkey tom performance assessed through: body weight, feed consumption, feed efficiency, mortality, and flock uniformity.
- To determine the effects of SD on turkey tom health and wellbeing assessed through: footpad lesion scores, subjective gait scores, feather condition and cleanliness scores, heterophil/lymphocyte ratios, and core body temperature.
- To determine the effects of SD on turkey tom behaviour as an additional tool for assessing welfare.

1.7 Hypotheses

Increasing SD through increasing the bird group size is a stressor for heavy turkey toms, and will increase aggression and competition. In addition to this reduction in wellbeing, the stress will result in a negative impact on bird health and performance:

- Body weight will be reduced and feed efficiency will be negatively impacted;
- Flock uniformity will be poorer;
- Mortality due to illness and due to aggression will increase as a result of decreased immune function and altered aggressive behaviours;
- Heterophil/lymphocyte ratios will increase.

Increasing the group size will also alter the group dynamics and decrease the space per bird resulting in alterations to bird behaviour and health:

- Feather condition will be poorer and birds will be dirtier as a result of increasing density;
- Gait score (mobility) will be negatively impacted due to the alteration of available space, as a result exercise behaviours such as walking will decrease;
- Footpad lesion incidence and severity will be negatively impacted as a result of decreased space allowances;
- Comfort behaviours will decrease in birds at higher densities due to limited space and stress.

2.0 Chapter 2: Assessing the effects of stocking density on turkey tom productivity to 16 weeks of age

The objectives of this work were to provide a well-rounded assessment of the effects of SD on turkey toms to 16 wk of age. Chapter 2 focuses on the effects of increasing SD on turkey tom productivity to 16 wk of age using body weight, feed intake, feed efficiency, uniformity, and mortality as performance indicators.

2.1 Abstract

Stocking density (SD) is one of the primary drivers of economic return in poultry production. While broiler SD has been examined in depth, the effects of increasing density on turkey tom performance are much less known. Two trials (blocks), each consisting of 1,434 Nicholas Select turkey toms were conducted to evaluate the effects of graded levels of SD (30, 40, 50, and 60 kg/m^2) on turkey tom performance to 16 wk of age. Birds were housed in large open rooms (8 in total and 2 per SD treatment per block), and carbon dioxide and ammonia were used as indicators of air quality. Ventilation was adjusted to balance these parameters across all rooms. Within each trial, body weight and feed consumption were recorded at 0, 4, 8, 12, and 16 wk of age. Body weight gain, feed-to-gain ratio (F:G), and mortality corrected feed-to-gain ratio ($F:G^m$) ratio were calculated for each 4 wk interval. Uniformity was assessed at 12 and 16 wk of age for 20 birds per replicate. Mortality and culled birds (beginning on d 11) were recorded daily and sent for necropsy to determine cause of death or sickness. Regression analyses were performed to determine the relationship between SD and measured variables (Proc Reg to test for linear and Proc RSReg to test for quadratic relationships in SAS 9.4). Differences were considered significant when $P \leq 0.05$ and trends were noted when $P \leq 0.10$. Body weight decreased as SD increased at both 12 (quadratic) and 16 wk (linear). Body weight gain decreased in the last four weeks (12-16, linear) and over the course of the trial (0-12, quadratic; 0-16, linear) as SD increased. Feed consumption demonstrated a linear relationship with increasing SD, increasing from wk 4-8 and decreasing from wk 12-16. The $F:G^m$ ratio increased linearly with increasing SD for all time periods beginning at wk 4. Flock uniformity and total percent mortality were unaffected by SD. An economic analysis was conducted, demonstrating increasing monetary gains with increasing SD. Overall, increasing SD negatively impacts bird performance including body weight, body weight gain, feed consumption, and feed efficiency. Other measures of performance such as overall mortality and flock uniformity were not affected.

Key words body weight gain, feed efficiency, uniformity, mortality

2.2 Introduction

Stocking density (SD) is an important aspect of turkey management as it can have a large impact on the producer's economic return as well as on the bird's health and wellbeing. Although turkey SD is much less studied when compared to broiler chicken SD, the majority of the studies have examined bird performance in relation to increasing density. Research has consistently shown decreases in body weight with increasing SD (Coleman and Leighton, 1969; Proudfoot et al., 1979b; Denbow et al., 1984; Noll et al., 1991). This decrease in body weight could be attributed to increased competition at the feeder, increased stress due to changes in group size or changes in the environment quality, or due to the bird's inability to move around in their pen. While the results on the impact of varying SD on feed efficiency are less consistent, certain studies have shown decreased feed efficiency with increasing SD (Denbow et al., 1984; Noll et al., 1991), while others have shown no effects (Coleman and Leighton, 1969; Proudfoot et al., 1979b). Effects on body weight and feed efficiency are important economically as they both translate directly to producer income and expense, however poor performance may also indicate that birds are experiencing stress. Mortality has shown no significant differences when evaluated in relation to SD, although numerical differences (Coleman and Leighton, 1969) and tendencies for increased mortality at high SD have been noted (P<0.06; Noll et al., 1991).

Environment can also play a role in bird performance, as increasing density increases bird impact on the housing environment resulting in changes in air quality and litter characteristics. These environmental changes in turn, impact bird health and bird performance (Dawkins et al., 2004). Litter moisture has been shown to increase as bird density increases due to the larger volume of excreta being produced (Coleman and Leighton, 1969; Noll et al., 1991). Litter moisture has also been related to an increase in ammonia production from the litter, which is a concern for bird health and productivity (Ritz et al., 2004). Other measures of air quality, such as carbon dioxide, can be used as an indicator of environmental quality in relation to SD. Increased levels of carbon dioxide are typically related to an increase in density as it is the output of respiration (Zuidhof et al., 1993). In addition, carbon dioxide can be used as an indicator of the ventilation rate it corresponds to air flow throughout the barn (Bennett, 2007). These factors are important to consider for SD studies as they present confounding factors which may impact the performance of the birds.

As turkeys are marketed at various body weights, reflective of their end use, it is important to consider the effects of SD not only on heavy toms but also on lighter birds. The current Canadian recommendations for turkey SD vary based on bird body weight and management conditions, ranging from 50-60 kg/m^2 (birds weighing 10.8-13.3 kg) to 55-65 kg/m^2 (birds weighing over 13.3 kg) (NFACC, 2016). The objectives of this chapter were to examine the effects of SD on turkey tom performance to 16 wk of age and to provide an economic analysis, which could then provide data to assist in the decision making processes for determining SD recommendations. It was hypothesized that increasing density would negatively impact turkey body weight, feed efficiency, flock uniformity, and mortality level. Also, high stocking rates would support greater economic return.

2.3 Materials and Methods

The experimental procedures for this experiment were approved by the University of Saskatchewan's Animal Care Committee and adhered to the guidelines set out by the Canadian Council on Animal Care (1993, 2009).

2.3.1 Experimental design

Research on the impact of graded levels of SD in relation to turkey tom productivity was conducted in one experiment, with two blocked trials resulting in four replicates per treatment. The two 16 wk trials took place starting in December of 2015 and 2016, and four levels of predicted final SD (30, 40, 50, and 60 kg/m^2) were evaluated for their effect on turkey tom productivity.

2.3.2 Birds and housing

A total of 1,434 Nicholas 85X700 (Nicholas Select) turkey toms were obtained from a commercial hatchery for each trial, and received both beak and toe treatments (three forward facing toes) at hatch. Birds were randomly allocated to one of four SD treatments. The number of birds housed per treatment was calculated based on the predicted body weight of the birds at 16 wk of age (Aviagen, 2015a) with an additional five percent included to account for mortality. Based on predicted SD of 30, 40, 50, and 60 kg/m^2 a total of 122, 161, 198, and 236 turkey poults were placed respectively in each room.

Birds were housed in large open, independently environmentally controlled rooms (6.7 m x 10.0 m = 67.5 m^2) and were brooded on wood shavings with a wheat straw base 7-10 cm thick, then straw for the rearing period. Brooder rings approximately 7.0 m in diameter were used for the first 10 d (trial 2) and 11 d (trial 1) and supplemental feeders and drinkers were provided throughout the first 10 d in both trials. Birds were fed ad libitum using aluminum tube feeders with a diameter of 36 cm for the first 38 d in both trials and 44 cm for the remainder of the trial. Water was provided using Lubing EasyLine™ pendulum turkey nipple drinkers (Lubing, Cleveland, TN). Feeder and drinker space was allocated on a per bird basis for each treatment, so that regardless of density, all birds had the same feeder and drinker space (15 birds/feeder; 20 birds/nipple). Birds were fed commercial diets (Table 2.1) and each diet was fed in specific quantities (kg/bird; Table 2.2). Diet changes were made when the ration was finished, and those dates were recorded. Total feed amount was adjusted to account for mortality when each diet change was made.

Lighting was provided by incandescent bulbs. Lighting duration was initially 23L:1D and 40 lux for the first two days and then decreased gradually to reach 18L:6D and 10 lux at 7 d of age. Dawn and dusk periods were simulated by gradually increasing and decreasing light intensity over a 15 minute period within the photoperiod. Light intensity was further reduced in all rooms to 5 lux at 31 d (trial 1 and 2) and 3 lux at 95 d (trial 1) and 87 d (trial 2) to discourage injurious pecking. Room temperature was maintained by hot water pipes along three walls of the room. Temperature during the initial brooding period (0-7d) was set at 29.0°C, then decreased by 2.0°C every week until a temperature of 13.0°C was reached at 91d. Temperature in trial 2 was increased 0.5°C in wk 1 and 1.0°C in wk 2 to account for cold ambient temperatures, and was decreased by 1.5°C on wk 3 back to the temperature curve used in trial 1. Heat lamps were placed above the brooder rings for the first 14 d in trial 1 and the first 19 d in trial 2 due to cold ambient temperature. Temperature was also lowered with the aim of reducing the incidence of aggressive damage, the temperature curve was lowered by 2.0°C at 64 d (trial 1 and 2) to reach a final set point of 11.0°C at wk 13.

Relative humidity and temperature were monitored hourly throughout the trial using iButton Hygrochron™ temperature and humidity data loggers (Maxim Integrated; San Jose, CA). Average weekly temperature was calculated on a per room basis over the course of the trial.

Humidifiers were placed in each room for the first week to increase RH to approximately 50%, as recommended by Aviagen (2015b). Carbon dioxide was monitored twice per week using a handheld CO_2 meter (CO240; Extech Instruments; Nashua, NH) until variability amongst rooms was greater than 20%. The ventilation rate was then adjusted to balance carbon dioxide concentration across all rooms. Thereafter, carbon dioxide was monitored three times a week and ventilation was adjusted as noted above. Ammonia was also monitored on a weekly basis, using ammonia Dräger-Tubes and a handheld pump (Draeger, Inc.; Houston, TX) until differences were noted. Ammonia was then monitored biweekly, and ventilation was adjusted accordingly when differences greater than 5ppm across individual rooms were noted.

Environmental enrichment was provided by placing intact square straw bales in the room. One straw bale was provided for every 40 birds. Birds were checked twice daily for mortality, culls, and aggressive damage (includes wounds or bleeding as a result of pecking or feather removal). Birds with minor wounds due to feather/aggressive pecking were treated with a deterrent (pine tar). Additionally, any straw bales that were destroyed were replaced and the broken bales were spread throughout the room, no additional litter management was used. All mortality and culls were replaced with extra poults until d 11 when the brooder rings were removed to best predict final SD. During the final two weeks of the trial, when SD was crucial, additional space was blocked off to remove additional space created by mortality losses.

2.3.3 Data collection

Body weight was recorded at 0, 4, 8, 12, and 16 wk of age and body weight gain was calculated for each time interval. Feed consumption was recorded at wk 4, 8, 12, and 16 and the feed-to-gain ratio and the mortality corrected feed-to-gain ratio were calculated for each time period. Birds that were runts, had skeletal abnormalities, were sick, or had damage due to aggression were culled. Beginning on d 11 (once bird replacement was done), all mortality and culled birds were recorded daily and birds were sent for necropsy to an independent diagnostic laboratory to determine cause of death or illness. Mortality was categorized according to aggression, metabolic, infectious, unknown, mechanical, skeletal, and other causes (Table 2.3). Flock uniformity was evaluated by individually weighing 20 randomly selected birds per replicate on wk 12 and 16. Net Income for both trials was calculated as follows: Net income = (Number shipped*Average BW* meat price) - (Number placed*Poult cost) - (Feed cost). The cost of the diets from the second trial were used in the economic analyses and are shown in Table 2.2. These costs were used to calculate the cost of feed based on the amount of diet fed to each replicate. The poult cost was $2.30 and the income per kilogram of live weight was $1.929.

2.3.4 Statistical analyses

The experiment was designed in a randomized complete block design (block as trial). Analyses were conducted using regression analysis (Proc Reg and RSReg; SAS 9.4®, Cary, NC) to assess the linear and quadratic relationships between treatment and dependent variables. Data were checked for normality using Proc UNIVARIATE in SAS (SAS®9.4, Cary, NC) and log transformed (log +1) when necessary. An analysis of variance was conducted for weekly room temperature using Proc Mixed (SAS 9.4®, Cary NC). Differences were considered significant if $P \leq 0.05$ and trends were noted when $P \leq 0.10$.

Table 2.1. Ingredients and calculated nutrient content of diets fed to turkey toms from 0-16 weeks of age

Ingredients (%)	Starter 1	Starter 2	Grower 1	Grower 2	Grower 3	Finisher
Wheat	26.12	25.00	25.00	25.00	25.00	29.51
Corn	7.62	16.80	23.96	22.83	27.65	30.00
Soybean meal (48%)	29.99	26.00	21.69	15.38	11.40	9.41
Corn gluten meal	15.00	15.00	13.54	20.00	20.00	17.35
Meat meal	5.00	3.00	2.00	4.36	4.35	2.00
Fish meal	4.93	5.00	5.00	4.58	4.00	4.00
Canola meal	4.00	2.00	2.00	2.00	2.00	2.00
Canola oil	3.80	3.80	3.80	3.80	3.80	3.80
Limestone	1.34	1.32	1.15	0.96	0.76	0.82
Monocalcium phosphate	0.66	0.59	0.42	0	0	0
Salt	0.11	0.13	0.16	0.17	0.18	0.20
Vit./min. premix[1]	0.25	0.21	0.19	0.18	0.18	0.16
Selenium	0.14	0.15	0.14	0.14	0.14	0.14
DL-Methionine	0.10	0.07	0.06	0	0	0
L-Lysine HCl	0.47	0.46	0.45	0.28	0.25	0.32
Pro-Bond (pea starch)	0.15	0.10	0.13	0.14	0.13	0.09
Sodium bicarbonate	0.16	0.16	0.13	0.06	0.04	0.06
BMD 110 G[2]	0.05	0.05	0.05	0.05	0.05	0.05
Rumensin[3]	0.50	0.05	0.05	0	0	0
Ronozyme[4]	0.03	0.03	0.03	0.03	0.03	0.03
Endofeed W[5]	0.02	0.02	0.02	0.02	0.02	0.02
Vitamin E 50	0.01	0.01	0.002	0.003	0.003	0
Biotin concentrate (2%)	0.001	0.001	0	0	0	0
Calculated composition (%)						
ME (kcal/kg)	3,020	3,100	3,150	3,250	3,300	3,350
Crude protein	34.6	29.7	26.0	29.5	27.6	24.8
Sodium	0.170	0.165	0.160	0.155	0.150	0.150
Calcium	1.49	1.38	1.24	1.14	1.00	0.93
Available phosphorus	0.76	0.69	0.62	0.57	0.50	0.51
Lysine	1.73	1.53	1.37	1.21	1.08	0.99
Methionine	0.664	0.609	0.585	0.496	0.475	0.47
Methionine + cysteine	1.120	1.010	0.920	0.896	0.860	0.808

[1] Supplied per kilogram of diet: retinol, 2.83 mg; cholecalciferol, 0.076 mg; d-α tocopherol, 33.6 mg; menadione, 1.43 mg; thiamine, 1.95 mg; riboflavin, 6.5 mg; niacin, 65 mg; pyridoxine, 3.25 mg; cobalamine, 0.013 mg; pantothenic acid, 13.0 mg; folic acid, 1.1 mg; biotin, 0.163 mg; antioxidant, 0.081 mg; iron, 55 mg; zinc, 60.5 mg; manganese, 74 mg; copper, 5.5 mg; iodine, 0.72 mg; and selenium, 0.3 mg. [2]Bacitracin Methylene Disalicylate (Zoetis Canada Inc, Kirkland, Canada). [3]Active ingredient: monensin sodium (Elanco, Greenfield, IN). [4]Phytase enzyme, 2,500 FYT/g (DSM Nutritional Products, Heerlen, the Netherlands). [5]β-glucanase, 700 activity units/g and xylanase enzymes 2,250 activity units/g (GNC Bioferm Inc., Bradwell, Canada).

Table 2.2. Diet cost used in economic analysis, amount of diet fed (kg/bird) and physical feed form given to turkey toms from 0-16 weeks of age

Diet name	Feed form	Amount fed	Diet cost ($/tonne)[2]
Starter 1	Crumble	1.65	653
Starter 2	Crumble	2.55	570
Grower 1	Small pellet	6.25	506
Grower 2	Pellet	9.50	510
Grower 3	Pellet	7.70	503
Finisher[1]	Pellet	15.25	446

[1]All other diets were fed on a kg per bird basis, finisher was fed from the time Grower 3 was finished until the end of trial with an average of 15.25 kg/bird and a range of 13.50-16.40 kg/bird.
[2]Prices as of 2017 (Federated Co-op Ltd., Saskatoon, Canada).

Table 2.3. Mortality and culls diagnosis categories

Category	Diagnosis
Aggression	Head/neck pecked, wing pecked, and/or snood pulled
Metabolic	Ascites, chronic heart, right ventricular heart disease, round heart disease, slipped tendon, aortic rupture, peri-renal hemorrhage, hemorrhagic fatty liver syndrome
Infectious	Arthritis, synovitis, cellulitis, hepatitis, endocarditis, pericarditis, peritonitis, splenitis, keel bursitis, bursitis, enlarged hock joints
Unknown	No visible lesion
Mechanical	Broken wing, broken leg, ruptured tendon, trauma
Skeletal	Rickets, valgus varus, rotated tibia, spondylolisthesis, tibial dyschondroplasia
Other	Impaction, hepatomegaly, lateral tibial tarsal ligament rupture, enlarged kidney, enlarged spleen

2.4 Results

The actual SD achieved at each time period is shown in Table 2.4. At wk 16, the average final SD achieved was 32.03, 42.56, 53.77, and 62.24 kg/m^2. The carbon dioxide concentration (ppm) for both trial 1 and 2 are shown in Table 2.5. Although not statistically analyzed, these figures demonstrate that the CO_2 concentration over time were relatively consistent across treatments, illustrating that adjustments to the ventilation during the trials allowed for similar ventilation rates on a per bird basis. As a result air quality was similar across SD treatments. It is also important to note that drops in external ambient temperature typically resulted in spikes in the CO_2 concentration across all treatments, likely as a result of reduced ventilation to allow rooms to maintain internal temperature set points. Ammonia concentration (ppm) for both treatments are shown in Table 2.5. Ammonia concentrations follows a similar pattern to CO_2, with relative concentrations across treatments staying fairly consistent. Again, as external ambient temperature drops, the concentration of ammonia increased due to decreases in ventilation rates to allow internal room temperature to be maintained. Both CO_2 and ammonia concentrations show that air quality across all treatments followed similar patterns, indicating consistent air quality across increasing SD treatments, thus removing the impact of variance in CO_2 and ammonia on measured variables. The average weekly temperature demonstrated no significant differences across SD treatments over the 16 wk period (Table 2.6).

2.4.1 Body weight

Poult body weight at placement was similar across rooms and treatments (Table 2.7). Body weight was not affected by density treatment at both 4 and 8 wk of age. At 12 wk, body weight demonstrated a decreasing quadratic relationship (P=0.04) with increasing density (12.59, 12.65, 12.61, and 12.40 kg for treatments 30, 40, 50, and 60 kg/m^2, respectively). Final body weight at wk 16 decreased in a linear fashion (P=0.01) as SD increased (18.78, 18.71, 18.55, and 18.13 kg for treatments 30, 40, 50, and 60 kg/m^2, respectively). Body weight gain showed no differences between treatments from 0-4 wk of age (Table 2.8). For wk 4-8 and 8-12 there was a tendency for body weight to decrease as SD increased (P=0.10, quadratic for wk 4-8 and P=0.10, linear for wk 8-12). Body weight gain was significantly lower with increasing densities from wk 12-16 (P=0.01, linear). Overall body weight gain for 0-12 wk decreased significantly in a quadratic fashion as SD increased (12.53, 12.59, 12.55, and 12.34 for 30, 40, 50, and 60 kg/m^2, respectively; P=0.03). Body weight gain for 0-16 wk was also significantly impacted, with a decreasing linear relationship as SD increased (18.72, 18.65, 18.49, and 18.07 for 30, 40, 50, and 60 kg/m^2, respectively; P=0.01).

2.4.2 Feed consumption and feed efficiency

Feed consumption was not significantly different between treatments from 0-4 and 8-12 wk of age (Table 2.9). Feed consumption from wk 4-8 increased with increasing SD (P=0.01, linear). Feed consumption during the last 4 wk (12-16) of the trial decreased significantly as SD increased (P=0.04, linear). The overall feed consumption (0-12 and 0-16 wk) was not significantly different with increasing SD.

Feed efficiency (without mortality correction), as shown in Table 2.10, was not significantly impacted by increasing SD from 0-4, 8-12, and 12-16 wk. The feed-to-gain ratio demonstrated a linear increase with increasing SD at one four week interval (4-8 wk, P=0.01). The overall feed-to-gain ratio for 0-12 increased linearly with increasing SD (P=0.02) and demonstrated a quadratic relationship for 0-16 wk with the highest value observed at 60 kg/m^2 (P=0.04). Mortality corrected feed efficiency was not significantly affected by increasing SD within the first four weeks as shown in Table 2.10. From wk 4-8, 8-12, and 12-16 there was a linear increase in the feed-to-gain ratio as SD increased (P<0.01, P=0.02, and P=0.03, respectively). The overall mortality corrected feed-to-gain ratio was also significantly impacted by SD for both 0-12 and 0-16 wk demonstrating a linear increase with increasing density (P=0.01 and P=0.02, respectively).

2.4.3 Uniformity

Body weight uniformity, as shown in Table 2.11, was expressed as the percentage of birds found within 5, 10, and 15% of the mean. There were no significant effects on flock uniformity in relation to increasing SD.

2.4.4 Mortality

Total mortality (d 11-16 wk) as a percentage of birds placed was not affected by SD treatment (Table 2.12). From wk 4-8 there was a tendency for mortality to be higher as SD increased (P=0.08, linear). Total mortality and culls categorized by cause was not impacted by increasing levels of SD (Table 2.13). Mortality and culls associated with aggression and infectious causes were the only categories impacted by increasing SD when examined by each 4 wk period (Table 2.14). Infectious related mortality/culls showed higher mortality at high SD from 8-12 wk of age (linear, P=0.04), as well as a quadratic tendency from d 11-4 wk (P=0.09) with infectious associated mortalities/culls highest at 30 and 60 kg/m^2. Aggression related mortality/culls increased linearly with increasing SD from 4-8 wk of age (P<0.01; trend quadratic P=0.08). Although not statistically significant, from d 11-4 wk aggression related mortality/culls only occurred at the highest SD (60 kg/m^2). At older ages, aggression associated mortality and culls demonstrated the opposite trend with a decreasing linear pattern with increasing levels of SD (P=0.09 from 12-16 wk).

2.4.5 Economic analysis

An economic analysis was conducted using poult cost, feed cost, number of birds shipped, and bird income in calculations (Table 2.15). Overall, higher SD supports higher monetary return (1,058.01, 1,478.50, 1,881.49, and 1,925.28 for treatments 30, 40, 50, and 60 kg/m^2, respectively; P=0.01, quadratic).

Table 2.4. Average stocking density (kg/m^2) achieved at 4, 8, 12, and 16 weeks of age

Age (wk)	n	Estimated final stocking density (kg/m^2)			
		30	40	50	60
4	4	2.72	3.69	4.52	5.43
8	4	11.01	15.00	18.57	21.92
12	4	21.72	29.29	36.51	42.30
16	4	32.03	42.56	53.77	62.24

Table 2.5. Average carbon dioxide and ammonia concentration (ppm) in relation to estimated stocking density in 16 week old turkey toms

Parameter	Estimated final stocking density (kg/m^2)			
	30	40	50	60
Trial 1				
Average CO_2 (ppm)	1366	1397	1471	1548
CO_2 Range (ppm)	498-3461	483-3010	503-2827	513-2956
Average Ammonia (ppm)	7.8	8.7	8.1	7.7
Ammonia Range (ppm)	0-35	1-20	2.5-20	2.5-15
Trial 2				
Average CO_2 (ppm)	1651	1639	1727	1723
CO_2 Range (ppm)	428-3677	454-3207	455-3012	475-3233
Average Ammonia (ppm)	9.8	12.6	12.1	11.5
Ammonia Range(ppm)	0-25	0-25	2.5-30	0-25

Trial 1 CO_2 measurements were from d 1-112 and ammonia measurements were from d 63-112.
Trial 2 CO_2 measurements were from d 1-111 and ammonia measurements were from d 45-111.

Table 2.6. Average weekly temperature (°C) across estimated final stocking density treatments from 1 to 16 weeks

Age (wk)	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value[2] (ANOVA)
		30	40	50	60		
1	4	28.2	27.9	28.4	28.1	0.11	0.57
2	4	27.1	26.7	27.0	26.5	0.14	0.34
3	4	26.1	25.0	25.2	24.6	0.28	0.09
4	4	23.9	23.6	23.7	23.0	0.18	0.11
5	4	22.6	22.3	22.5	22.0	0.14	0.48
6	4	21.1	20.8	20.9	20.6	0.11	0.35
7	4	20.3	19.9	19.9	19.2	0.19	0.24
8	4	19.3	18.9	19.2	18.9	0.11	0.54
9	4	17.7	17.7	18.0	17.9	0.12	0.77
10	4	15.8	15.7	15.9	15.4	0.13	0.47
11	4	14.6	14.1	14.5	13.5	0.16	0.06
12	4	13.0	12.7	13.0	12.7	0.13	0.74
13	4	10.8	10.6	11.0	10.9	0.30	0.77
14	4	10.8	11.1	11.3	11.5	0.34	0.44
15	4	11.8	11.9	12.4	12.5	0.57	0.41
16	4	10.7	10.5	10.5	10.3	0.22	0.93

[1]Standard error of the mean.
[2]ANOVA considered significant if $P \leq 0.05$.

Table 2.7. Effect of estimated final stocking density on turkey tom body weight (kg) at 0, 4, 8, 12, and 16 weeks of age

Age (wk)	n	Estimated final stocking density (kg/m^2)				SEM[1]	*P*-value (Linear)	*P*-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
0	4	0.06	0.06	0.06	0.06	0.0004	0.25	0.26	-
4	4	1.49	1.51	1.48	1.49	0.020	0.90	0.88	-
8	4	6.12	6.23	6.21	6.20	0.031	0.44	0.40	-
12	4	12.59	12.65	12.61	12.40	0.036	0.06	0.04	$Y=-0.67e^{-3}x^2+0.05x+11.55$
16	4	18.78	18.71	18.55	18.13	0.098	0.01	0.29	$Y=-0.02x+19.49$

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

Table 2.8. Effect of estimated final stocking density on turkey tom body weight gain (kg) from 0-4, 4-8, 8-12, 12-16, 0-12, and 0-16 weeks of age

Age (wk)	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
0-4	4	1.43	1.45	1.42	1.43	0.020	0.88	0.87	-
4-8	4	4.63	4.72	4.72	4.71	0.016	0.08	0.10	-
8-12	4	6.47	6.42	6.40	6.20	0.056	0.10	0.47	-
12-16	4	6.19	6.06	5.94	5.73	0.070	0.01	0.76	$Y=-0.02x+6.66$
0-12	4	12.53	12.59	12.55	12.34	0.036	0.06	0.03	$Y=-0.68e^{-3}x^2+0.06x+11.48$
0-16	4	18.72	18.65	18.49	18.07	0.098	0.01	0.29	$Y=-0.02x+19.43$

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

Table 2.9. Effect of estimated final stocking density on turkey tom feed consumption (kg) from 0-4, 4-8, 8-12, 12-16, 0-12, and 0-16 weeks of age

Age (wk)	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
0-4	4	1.86	1.86	1.86	1.87	0.032	0.90	0.93	-
4-8	4	7.25	7.43	7.46	7.52	0.037	0.01	0.35	$Y=0.83e^{-2}x+7.04$
8-12	4	14.79	14.74	14.73	14.70	0.081	0.71	0.95	-
12-16	4	20.34	19.54	19.47	19.25	0.186	0.04	0.40	$Y=-0.03x+21.15$
0-12	4	23.91	24.03	24.05	24.09	0.069	0.36	0.79	-
0-16	4	44.24	43.57	43.51	43.35	0.210	0.15	0.55	-

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

Table 2.10. Effect of estimated final stocking density on turkey tom feed-to-gain ratio and mortality corrected feed-to-gain ratio from 0-4, 4-8, 8-12, 12-16, 0-12, and 0-16 weeks of age

Age (wk)	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
Feed-to-gain (F:G)									
0-4	4	1.30	1.29	1.31	1.31	0.006	0.33	0.34	-
4-8	4	1.57	1.58	1.59	1.61	0.006	0.01	0.36	$Y=0.12e^{-2}x+1.54$
8-12	4	2.39	2.39	2.38	2.46	0.021	0.31	0.37	-
12-16	4	3.93	3.80	3.65	3.91	0.065	0.74	0.15	-
0-12	4	1.91	1.91	1.92	1.95	0.007	0.02	0.15	$Y=0.14e^{-2}x+1.86$
0-16	4	2.49	2.45	2.44	2.51	0.013	0.76	0.04	$Y=0.27e^{-3}x^2-0.02x+2.98$
Feed-to-gain mortality corrected (F:G^m)									
0-4	4	1.29	1.28	1.30	1.30	0.004	0.21	0.32	-
4-8	4	1.55	1.57	1.57	1.58	0.003	<0.01	0.63	$Y=0.76e^{-3}x+1.53$
8-12	4	2.25	2.27	2.28	2.35	0.015	0.02	0.31	$Y=0.30e^{-2}x+2.15$
12-16	4	3.20	3.21	3.27	3.35	0.027	0.03	0.51	$Y=0.51e^{-2}x+3.03$
0-12	4	1.88	1.88	1.89	1.92	0.006	0.01	0.32	$Y=0.15e^{-2}x+1.83$
0-16	4	2.29	2.29	2.31	2.35	0.010	0.02	0.31	$Y=0.20e^{-2}x+2.22$

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.

Table 2.11. Effect of estimated final stocking density on turkey tom flock uniformity expressed as the percentage of birds found within 5, 10, and 15% of the mean body weight at 12 and 16 weeks of age

	n	Estimated final stocking density (kg/m^2)				SEM[1]	CV	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60					
Week 12(% within x of the mean)										
5	4	60.00	61.25	53.75	57.50	3.191	18.00	0.45	1.00	-
10	4	85.00	88.75	91.25	85.00	1.882	11.76	0.87	0.21	-
15	4	96.25	96.25	100.00	95.00	1.434	4.97	0.94	0.41	-
Week 16 (% within x of the mean)										
5	4	50.00	61.25	46.25	56.25	2.571	19.24	0.85	0.95	-
10	4	86.25	86.25	73.75	85.00	2.139	10.33	0.41	0.17	-
15	4	95.00	96.25	91.25	93.75	1.226	5.21	0.44	0.79	-

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.

Table 2.12. Effect of estimated final stocking density on turkey tom percent mortality and culls (%) from day 11-4 weeks, 4-8, 8-12, 12-16, 0-12, and 0-16 weeks of age

Age	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
d 11-4 wk	4	1.84	1.40	1.26	1.59	0.316	0.75	0.70	-
4-8 wk	4	1.64	1.40	1.64	2.97	0.301	0.08	0.36	-
8-12 wk	4	3.89	3.57	3.16	3.28	0.392	0.72	0.92	-
12-16 wk	4	6.76	6.21	4.17	5.51	0.515	0.22	0.32	-
0-12 wk	4	7.38	6.37	6.06	7.84	0.647	0.64	0.40	-
0-16 wk	4	14.14	12.58	10.23	13.35	0.842	0.60	0.17	-

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

Table 2.13. Effect of estimated final stocking density on turkey tom percent mortality and culls (% of birds placed) by cause from day 11 to 16 weeks of age

Cause[3]	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (linear)	P-value (quadratic)	Regression Equation[2]
	30	40	50	60				
Aggression	5.12	3.88	3.28	4.56	0.449	0.44	0.21	-
Metabolic	2.25	3.26	1.77	2.54	0.357	0.89	0.74	-
Infectious	1.84	1.40	1.64	2.54	0.323	0.40	0.22	-
Unknown	2.66	1.86	1.77	1.59	0.332	0.37	0.97	-
Mechanical	1.23	0.93	0.50	1.38	0.250	0.81	0.28	-
Skeletal	0.41	0.62	0.76	0.42	0.117	0.89	0.30	-
Other	0.61	0.62	0.50	0.32	0.117	0.38	0.79	-

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

[3]Aggression: head/neck pecked, wing pecked, snood pulled; Metabolic: ascites, chronic heart, right ventricular heart disease, round heart disease, slipped tendon, aortic rupture, peri-renal hemorrhage, hemorrhagic fatty liver syndrome; Infectious: arthritis, synovitis, cellulitis, hepatitis, endocarditis, pericarditis, peritonitis, splenitis, keel bursitis, bursitis, enlarged hock joints; Unknown: no visible lesion; Mechanical: broken wing, broken leg, ruptured tendon, trauma; Skeletal: rickets, valgus varus, rotated tibia, kinky back, tibial dyschondroplasia; Other: foreign body, hepatomegaly, lateral tibial tarsal ligament rupture, enlarged kidney, enlarged spleen.

Table 2.14. Effect of estimated final stocking density on turkey tom percent mortality and culls (% of birds placed) by cause from day 11-4 weeks, 4-8, 8-12, and 12-16 weeks of age

% In category[3]	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (linear)	P-value (quadratic)	Regression Equation[2]
	30	40	50	60				
Day 11-4 weeks								
Aggression	0	0	0	0.11	0.026	0.19	0.32	-
Metabolic	0.41	0.78	0.25	0.21	0.163	0.44	0.64	-
Infectious	0.82	0	0.25	0.42	0.148	0.74	0.09	-
Unknown	0.41	0.31	0.13	0.53	0.121	0.97	0.39	-
Mechanical	0	0	0	0	-	-	-	-
Skeletal	0	0.16	0.25	0.21	0.072	0.28	0.45	-
Other	0.20	0.16	0.13	0	0.067	0.32	0.73	-
Week 4-8								
Aggression	0	0.31	0.38	2.01	0.235	<0.01	0.08	Y=0.06x-2.07
Metabolic	0.61	0.16	0.25	0.21	0.120	0.39	0.51	-
Infectious	0.41	0	0.63	0.32	0.145	0.64	0.84	-
Unknown	0.41	0.31	0.38	0.21	0.105	0.63	0.86	-
Mechanical	0	0.16	0	0.11	0.046	0.67	0.84	-
Skeletal	0.20	0.47	0.25	0.11	0.096	0.64	0.32	-
Other	0	0	0	0.11	0.026	0.19	0.32	-
Week 8-12								
Aggression	2.05	1.24	1.14	0.95	0.320	0.26	0.71	-
Metabolic	0.61	1.09	0.38	1.27	0.164	0.35	0.39	-
Infectious	0	0	0.25	0.32	0.067	0.04	0.85	Y=0.01x-0.40
Unknown	0.61	0.78	0.63	0.21	0.176	0.44	0.48	-
Mechanical	0.20	0.47	0.25	0.53	0.143	0.49	0.92	-
Skeletal	0.20	0	0.25	0	0.064	0.59	0.79	-
Other	0.20	0	0.25	0	0.064	0.59	0.79	-
Week 12-16								
Aggression	3.07	2.33	1.77	1.48	0.342	0.09	0.81	-
Metabolic	0.61	1.24	0.88	0.85	0.178	0.75	0.59	-
Infectious	0.61	1.40	0.50	1.48	0.252	0.37	0.64	-
Unknown	1.23	0.47	0.63	0.64	0.160	0.53	0.29	-
Mechanical	1.02	0.31	0.25	0.74	0.211	0.93	0.20	-
Skeletal	0	0	0	0.11	0.026	0.19	0.32	-
Other	0.20	0.47	0.13	0.21	0.103	0.76	0.70	-

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

[3]Aggression: head/neck/wing pecked, snood pulled; metabolic: ascites, chronic heart, right ventricular heart disease, round heart disease, slipped tendon, aortic rupture, peri-renal hemorrhage, hemorrhagic fatty liver syndrome; infectious: arthritis, synovitis, cellulitis, hepatitis, endocarditis, pericarditis, peritonitis, splenitis, keel bursitis, bursitis, enlarged hock joints; unknown: no visible lesion; mechanical: broken wing/leg, ruptured tendon, trauma; skeletal: rickets, valgus varus, rotated tibia, kinky back, tibial dyschondroplasia; other: foreign body, hepatomegaly, lateral tibial tarsal ligament rupture, enlarged kidney, enlarged spleen.

Table 2.15. Economic analysis of estimated final stocking density of turkey toms to 16 weeks of age (n=4)

Parameter per room	Estimated final stocking density (kg/m^2)				SEM[1]	*P*-value (Linear)	*P*-value (Quadratic)	Regression Equation[2]
	30	40	50	60				
Number placed	122	161	198	236	-	-	-	-
Poult cost ($)	280.60	370.30	455.40	542.80	-	-	-	-
Number shipped	104.75	140.50	177.75	204.50	-	-	-	-
Avg. Final BW (kg)	18.78	18.71	18.55	18.13	0.098	0.01	0.30	$Y=-0.02x+19.50$
Live wt. shipped (kg)	1,967.45	2,628.44	3,296.18	3,707.23	-	-	-	-
Bird income[3] ($)	3,795.21	5,070.26	6,358.32	7,151.24	-	-	-	-
Feed intake (kg)	4,957.82	6,491.84	8,118.03	9,442.03	-	-	-	-
Feed cost ($)	2,456.60	3,221.46	4,021.44	4,683.16	-	-	-	-
Net Income ($)[4]	1,058.01	1,478.50	1,881.49	1,925.28	94.935	<0.01	0.01	$Y= -0.93x^2+113.36x-1528.53$

[1]Standard error of the mean.
[2]Regression considered significant if $P\leq0.05$.
[3]Meat price per kilogram live weight used was $1.929.

2.5 Discussion and Conclusions

There are multiple inputs that impact bird performance and economic return, however SD is a large contributor to both. In terms of bird performance, body weight, feed efficiency, and culls/mortality all contribute significantly to economic return. Although there are few studies evaluating the impact of SD on turkeys, the majority of those conducted have included performance parameters.

The effects of increasing density on body weight and body weight gain in this study demonstrated lower body weights, especially as the birds are getting older, as SD increases and floor space becomes more limiting. The decrease in body weight at older ages with increasing SD is consistent with many of the previous studies (Coleman and Leighton, 1969; Proudfoot et al., 1979b; Denbow et al., 1984; Noll et al., 1991; Martrenchar et al., 1999). These data suggest that SD is less of a concern at younger ages with regards to mobility, as the bird is likely still able to move around and easily access feed and water as floor space is not restricted. As the bird ages and becomes heavier, access to feed and water may become more difficult as a result of decreased floor space and having to manoeuver through many pen mates to gain access. In addition, older birds (16 wk) demonstrated poorer mobility at higher densities, which may also reduce the motivation to gain access to resources (Chapter 3). It is important to note that in the present study as well as those mentioned above, the feeder and drinker space was provided on a per bird basis. Therefore we can state that feeder and drinker space alone is not responsible for the altered growth rate. Some other factors that may be impacting growth rate could include stress and immune function. An early study in 10-17 d old chicks demonstrated that exposure to multiple stressors resulted in both decreases in body weight as well as an increase in H/L ratio (McFarlane et al., 1989; McFarlane and Curtis, 1989). The authors noted that the reductions in body weight may be partially due to the reallocation of resources from processes such as growth and towards the stress response and increased immune response. In the present study, the H/L ratio was not significantly impacted at later ages (wk 12 and 16) however some of the health parameters, such as increases in footpad lesions and poorer gait score, may have been stressful (Chapter 3). When comparing the actual SD achieved at both 12 and 16 wk of age (21.72, 29.29, 36.51, and 42.30 kg/m^2 and 32.03, 42.56, 53.77, and 62.24 kg/m^2, respectively) to those recommended by the Canadian Codes of Practice (50-60 kg/m^2 and 55-65 kg/m^2, respectively)

(NFACC, 2016), it is important to note that even at the lower 12 wk SD, body weight is negatively impacted.

There are fewer studies which evaluate feed intake in relation to SD. Denbow et al. (1984) found no effect of SD on feed consumption to 12 wk, however from 12-18 and 12-20 wk the authors found that feed consumption decreased with increasing SD. A second study also demonstrated very similar results with increasing density, where no differences in feed intake were noted to 12 wk of age, however from 12-16 and 16-20 wk of age birds housed at higher SD consumed less feed (Noll et al., 1991). The authors also noted that the overall feed consumption (0-20 wk) was lower at higher SD. These findings are somewhat consistent with the findings in this study, as there was a decrease in feed consumption within the last 4 wk of the study (12-16 wk). Again, this is not due to available feeder space per se, as space was equalized among treatments in the present study, but may be due to greater difficulty moving throughout the room to access the feeder or due to poorer mobility at this age (Chapter 3). Of interest, feed consumption increased with increasing SD from 4-8 wk. The early increase in feed intake may be a result of the social nature of feeding behaviour in poultry. A study in broiler chickens found that birds were more likely to approach a feeder that was already occupied and would remain at the feeder longer when other birds were present (Collins and Sumpter, 2007). The authors suggested this may be partially due to breeding programs selecting for growth and feed intake and indirectly resulting in a higher selection of social facilitation behaviours. At younger ages the presence of a larger group size may result in an increased likelihood of a bird being found at a feeder, encouraging other birds to get up and feed more frequently. In older birds, although there may be an increased likelihood of a bird present, the difficulty associated with reaching the feeder may be responsible for the decrease in feed intake. In addition, decreases in mobility in older birds (Chapter 3) may demonstrate that although feeding is a social behaviour, poorer mobility may prevent older birds from participating in feeding activities. This is further supported as there was a smaller percentage of birds present at the feeder as SD increased, indicative of reduced feeding activity (Chapter 3).

Mortality corrected feed-to-gain demonstrated much more consistent results throughout the study compared to feed consumption, with linear increases in $F{:}G^m$ beginning at 4 wk of age (when floor space was not a limiting factor) and continuing throughout the course of the trial with increasing SD. Previous literature has shown mixed results for feed efficiency in relation to turkey SD. Coleman and Leighton (1969) and Proudfoot et al. (1979) found no effect of increasing SD on feed efficiency. Denbow et al. (1984) and Noll et al. (1991) noted that feed efficiency was poorer for higher SD, with differences noted at 8 wk of age and older. In all of the studies listed above, feeder and drinker space were provided on a per bird basis suggesting that feeder space or lack of space is not a confounding factor impacting the bird's ability to gain access to feed. Although feed efficiency may not be directly linked to feeder space, the ability for birds to access feed and water with minimal stressors may contribute to improvements in feed efficiency. Moran (1985) found that feed-to-gain was negatively impacted by increasing SD from 12 to 38 d and from 92 to 119 d (12.7 to 24.7 kg/m^2), however feeder space was not equalized in this study and could be a confounding factor. Similar to the effects seen on body weight, McFarlane et al. (1989) found decreases in feed efficiency of chicks exposed to multiple stressors. The effects on feed efficiency early on support the increase in the H/L ratio early on, as a measure of chronic stress (Chapter 3). In addition, feather cover and cleanliness decreased with increasing SD (Chapter 3), and as a result a greater amount of energy may have been directed towards thermoregulation, decreasing feed efficiency which has previously been seen in laying hens (Leeson and Morrison, 1978). The negative impact of SD on feed efficiency is not likely a result of activity levels, as birds at lower SD demonstrated more birds walking as well as improvements in walking abilities (Chapter 3).

The overall mortality did not differ by SD treatment, however finding statistically different results in relation to mortality is difficult as a result of low mortality rates. As a result, non-significant findings may not accurately demonstrate the impact of density on bird mortality. The numerical values seen with increasing SD demonstrate higher mortality in the lowest and highest SD treatments. Of note, two studies have seen numerically higher mortality in relation to high SD. Coleman and Leighton (1969) noted numerical differences with greater mortality levels at high SD (no *P*-value reported). Noll et al. (1991) found similar results with a tendency for higher mortality at high SD. In the current study, high mortality and culling were seen at both extremes (30 and 60 kg/m^2) and may be due to increased activity levels in the low density and perhaps increased frustration due to lack of space or large group size in the high density rooms. Aggression related mortality and culls make up the highest proportion of mortality/culls by cause, with the highest incidence occurring in both 30 and 60 kg/m^2 over the course of the trial (not statistically significant). When evaluating aggression in relation to age, it is clear that the younger birds typically participated in higher incidences of aggression related mortality and culls at higher SD which may be related to the increases seen in the H/L ratio (wk 4) as a measure of chronic stress as well as the increased incidence of aggressive damage from wk 4-8 at high SD (Chapter 3). Furthermore the trend seen at older ages suggests that aggression related mortality and culls in older birds occurred more frequently at low SD. This may be related to behavioural changes as space becomes more limiting such as increased percentage of birds walking (12, 14, and 16 wk) and strutting (14 wk) at low SD, suggesting that birds at low SD may be more active (Chapter 3). The increase in infectious related mortality and culls with increasing SD may be at least partially related to multiple health parameters such as cleanliness and foot pad lesions. Although only a hypothesis, it could be possible that feather cleanliness may play a role in infectious disease levels. The increased footpad lesions with increasing SD (Chapter 3) may also contribute to increased infectious related mortality as foot pad lesions have been associated with increases in secondary infections (Martrenchar et al., 2002).

Finally, flock uniformity was unaffected by increasing SD. To the best of author's knowledge, flock uniformity data in relation to turkey SD has not been previously studied. However, in broilers some of the literature demonstrates poorer flock uniformity at lower densities (Feddes et al., 2002). The authors noted that the birds at low densities were also heavier on average, suggesting that the birds at low densities were allowed to grow rapidly to reach their genetic potential. The birds at higher densities were perhaps more uniform as a result of space restrictions (Feddes et al., 2002). Feeding behaviour may also relate to uniformity. A study conducted in broiler chickens showed that birds were more likely to move towards a feeder and feed if there was already a bird present (Collins and Sumpter, 2007). As a result higher SD may increase the likelihood of finding a bird at the feeder and may act to synchronize feeding amongst birds resulting in a more uniform flock. The lack of significant differences in turkey tom uniformity in relation to SD may be a result of differences between species or possibly a result of fewer birds sampled (20 per pen vs. the entire pen).

Increasing graded levels of SD demonstrated poorer performance of turkey toms to 16 wk of age. It was hypothesized that increasing SD would result in reduced body weight, poor feed efficiency, increased mortality, and poor flock uniformity. While mortality and flock uniformity were not affected, body weight and feed efficiency were the most significantly impacted demonstrating that increasing SD to 60 kg/m^2 is detrimental to bird performance. Low or moderate densities (30 to 40 kg/m^2) may be ideal for maximizing bird performance. Despite the reduced performance however, the increased bird numbers overall demonstrate that higher densities will likely always be more profitable. It is important to note that economics do not take into consideration the effects of high densities on bird welfare, as a result bird health and wellbeing needs to be evaluated when making decisions regarding bird density. Other management factors must also be taken into consideration when selecting a target stocking density.

2.6 Acknowledgements

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3.0 Chapter 3: Assessing the effects of stocking density on turkey tom health and welfare to 16 weeks of age

Chapter 3 focuses on the impact that various SD have on the health and wellbeing of heavy toms. The parameters reported in this section include feather condition and cleanliness, footpad lesions, mobility, incidence of aggressive damage, H/L ratios, core body temperature, and behaviour. This data, in conjunction with that reported in Chapter 2, represent a multidisciplinary approach to developing a comprehensive data set on the effects of SD in male turkeys.

3.1 Abstract

Stocking density plays an important role in bird health and wellbeing as it can impact cleanliness, immune status, and behaviour of birds. There is little research focusing on SD of heavy toms and the impact it has on health and welfare. In this study, four graded levels of tom SD (30, 40, 50, and 60 kg/m^2) were evaluated in two 16 wk trials (n=2,868 Nicholas Select turkey toms). Birds were allocated to 8 large independently ventilated open rooms (6.71 x 10.06 m) based on final predicted body weight. Room temperature, humidity, carbon dioxide concentration and ammonia concentration were recorded throughout the trial and ventilation was adjusted to equalize across treatments. Mobility (subjective gait score, scale 0-5) was recorded at 12 and 16 wk on 20 birds per replicate. Footpad lesion score (scale 0-4), feather condition (scale 1-4) and cleanliness scores (scale 1-4) were recorded at 10, 12, and 16 wk of age on 20 birds per replicate. The incidence of aggressive injuries was recorded daily (trial 2 only) and birds were treated or culled depending on the level of damage. Heterophil/lymphocyte ratios were evaluated at 4, 12, and 16 wk of age as a measure of stress on 15 birds per replicate. Core body temperature was evaluated at 16 wk of age (trial 2 only, 3 birds per replicate) using iButtons (inserted into the crop/gizzard) and temperature transponders (injected subcutaneously on both the wing and breast). Finally, behaviour was recorded and scan sampled (field of view) at three ages 12 (trial 1 only), 14, and 16 wk. Mobility, footpad, feather score, aggressive damage, H/L ratio, and behaviour data were analyzed using regression analysis (linear (Proc REG) and quadratic relationships (Proc RSREG)) with the measured variable and SD. Core body temperature data was evaluated using an analysis of covariance with room temperature as the covariant and regression analyses for linear and quadratic relationships with SD. Differences were considered significant when $P \leq 0.05$ and trends were noted when $P \leq 0.10$. Mobility and footpad lesions were unaffected at 12 wk of age, however at 16 wk of age both mobility and footpad lesions were negatively affected by increasing SD (linear). Feather condition and cleanliness decreased linearly as SD increased at wk 10, 12, and 16. The incidence of aggressive damage was significantly higher as SD increased from wk 4-8 (quadratic). Heterophil/lymphocyte ratios increased linearly at 4 wk and followed the same trend at 12 wk. Core body temperature decreased with increasing SD (linear). Behaviour was impacted at 12 wk of age with standing behaviour showing a quadratic response, and walking and total disturbance showing a linear decrease. At 14 wk of age resting, preening, and comfort behaviours demonstrated a linear

increase, while walking and strutting demonstrated a linear decrease. Finally, at 16 wk of age resting, standing, walking, feeding, and total disturbance responded quadratically while preening behaviour increased linearly with increasing SD. These results suggest that increasing SD negatively impacts bird health and wellbeing through decreased mobility, increased footpad lesions, poorer feather condition and cleanliness, as well as through behavioural changes such as decreased mobility.

Key words feather condition, feather cleanliness, mobility, footpad lesions, heterophil/lymphocyte ratio

3.2 Introduction

Stocking density can have a large impact on bird health and wellbeing, which has often been documented in broiler chickens. Many of the studies evaluating turkey SD typically evaluate bird performance, however there are few studies which incorporate health and welfare parameters along with performance. Previous research concerning turkey SD has evaluated the effects on feather condition, mobility, footpad lesions, H/L ratios, and behaviour. However many of these studies only evaluate one or two of these parameters with production parameters being the primary focus.

Increasing SD may result in health challenges due to increased stress, alterations in environment, or alterations in group size. Early studies have shown that poorer feather cover is associated with increasing SD (Coleman and Leighton, 1969). Footpad lesions have also been studied in relation to SD, with an increasing incidence of footpad lesions at higher SD (Martrenchar et al., 1999). The increased incidence of footpad lesions has been shown to increase with high litter moisture (Martland, 1984), which has also been associated with increasing SD (Martrenchar et al., 1999). Martrenchar et al. (1999) also evaluated bird mobility, and found that as SD increased gait scores became poorer, indicative of poorer mobility. The authors hypothesized that this may be due to reduced activity, although it may also relate to the increased incidence of footpad lesions as they have been associated with pain in previous studies (Weber Wyneken et al., 2015). In addition to increased litter moisture, litter temperature has also been shown to increase at higher SD (Reiter and Bessei, 2000). As SD has been related to poorer bird mobility, it may be hypothesized that birds at higher SD may spend more time in contact with the litter and may result in higher core body temperatures. In addition, increases in core body temperature may also occur as a result of birds being in close contact with pen mates, which could potentially result in ventilation being less effective at bird level. Heterophil/lymphocyte ratios, considered to be a measure of chronic stress, have been evaluated more recently in relation to SD with no effects seen at 7, 12, 16, and 20 wk of age when birds were housed up to 58 kg/m^2 based on final predicted body weight (Hafez et al. 2015). Stocking density has previously been shown to increase the H/L ratio in broilers at 49 d of age, indicating SD may increase stress (Thaxton et al., 2006). Behaviour has been evaluated with increasing SD, indicating mixed results in relation to aggression, where certain studies have shown increases in aggression with decreased space allowance (Buchwalder and Huber-Eicher, 2004) others have seen increases in feather pecking at low SD (Gunthner and Bessei, 2006). In addition, other studies have seen no significant differences in aggression in relation to SD (Denbow et al., 1984; Martrenchar et al., 1999). Martrenchar et al. (1999) also noted no changes in walking activity with increasing SD.

The objectives of this chapter were to examine the effects of SD on turkey tom health and welfare to 16 wk of age. It is hypothesized that increasing SD will have negative effects on bird mobility, footpad lesions, and feather condition and cleanliness, as a result of increased litter moisture and reduced space allowances which may limit bird activity/exercise. Also, increasing density will result in increased stress triggering an increase in the heterophil/lymphocyte ratio. Finally, core body temperature will increase as a result of birds being space restricted and in closer contact with pen mates and the litter. As a result, bird behaviour, specifically mobility and comfort behaviours will be altered.

3.3 Materials and Methods

The experimental procedures for this experiment were approved by the University of Saskatchewan's Animal Care Committee and adhered to the guidelines set out by the Canadian Council on Animal Care (1993, 2009).

3.3.1 Experimental design

The impact of graded levels of SD in relation to turkey tom health and behaviour was evaluated through one experiment, consisting of two blocked trials resulting in a total of four replicates per treatment. Four levels estimated of final room SD (30, 40, 50, and 60 kg/m^2) were evaluated from placement to 16 wk of age.

3.3.2 Birds and housing

Turkey toms were obtained from a commercial hatchery for each trial (n=1,434; strain – Nicholas Select). The poults were toe (three forward facing toes) and beak treated at the hatchery, and then randomly allocated to one of four estimated final SD treatments. Bird numbers were determined using the predicted final body weight at 16 wk of age (Aviagen, 2015a) with five percent added to account for mortality (total number of 122, 161, 198, and 236 birds for treatments 30, 40, 50, and 60 kg/m^2, respectively). Birds were housed in 8 large individual rooms (6.7 m x 10.0 m = 67.5 m^2), that allowed for separate control of lighting, temperature and ventilation, resulting in a total of 4 room replicates per treatment over the course of both trials.

Poults were brooded on wood shavings with a wheat straw base 7-10 cm thick, followed by wheat straw for the rearing period. Brooder rings approximately 7.0 m in diameter were used for the first 10 and 11 d for trials 1 and 2, respectively. Ad libitum feed and water were provided throughout the course of the trial. Aluminum tube feeders with a diameter of 36 cm were used for the first 38 d and a diameter of 44cm for the remaining time. Water was provided using Lubing EasyLine™ pendulum turkey nipple drinkers (Lubing, Cleveland, TN). The number of feeders and nipple drinkers were provided on a per bird basis, allowing feeder and drinker space to be equal regardless of density. Supplemental feeders and drinkers were provided for the first 10 d in both trials. Birds were fed specific quantities (Table 2.2) of commercially available diets (formulation shown in Table 2.1). The dates of ration changes were recorded once a diet was finished and the following ration feed amounts were adjusted to account for total mortality the day prior to a ration change.

Incandescent bulbs were used as the lighting source, and day length started at 23L:1D and 40 lux for the first two days. The daylength was then decreased 1h each day to a final day length of 18L:6D and light intensity was gradually reduced to 10 lux by 7 d of age. Dawn and dusk periods were implemented throughout the course of the trial and were simulated by gradually increasing and decreasing light intensity over a 15 minute period. Rooms were heated via hot water pipes along three walls of the room, with a set point of 29.0°C for the first 7 d. Heat lamps were used as a supplemental heat source and were placed above the brooder ring for the first 14 d in trial 1 and 19 d in trial 2. Temperature decreased by approximately 2°C every week to a temperature of 13°C at 91d. In trial 2, the initial brooding temperature was adjusted (+0.5°C in wk 1 and +1.0°C in wk 2), however it was lowered back to the original curve in wk 3 (-1.5°C). Temperature and light intensity were further decreased in both trials to decrease the incidence of aggression. Light intensity was decreased to 5 lux at 31 d (trial 1 and 2) and further decreased to 3 lux at 95 d (trial 1) and 87 d (trial 2), while temperature curve was lowered by 2.0°C at 64 d (trial 1 and 2) reaching a set point of 11.0°C on wk13.

Temperature and humidity data loggers (iButton Hygrochron™; Maxim Integrated; San Jose, CA) were placed at bird level near the entrance of each room and recorded readings hourly throughout the trial. Average weekly temperature was calculated on a per room basis (Table 2.6). Relative humidity was increased in the first week by providing humidifiers in each room to target 50% RH (recommended by Aviagen, 2015b). Air movement was controlled through a negative-ventilation system, independently in each room. Air quality, including carbon dioxide (via handheld CO_2 meter CO240; Extech Instruments; Nashua, NH) and ammonia (via ammonia Dräger-Tubes and a handheld pump; Draeger, Inc.; Houston, TX) were monitored biweekly and weekly (respectively) until differences greater than 20% (CO_2) or 5 ppm (ammonia) were noted across treatments. Once differences were noted, monitoring became more frequent, and carbon dioxide was monitored three times a week and ammonia was monitored biweekly. If differences were noted across treatments, ventilation rates were adjusted in an attempt to equalize air quality across treatments (Summary in Table 2.5).

Additionally, intact square straw bales were provided (1 bale/40 birds) as environmental enrichment. Each room was checked twice daily for mortality and cull birds. At this time birds with minor aggressive damage were also treated using a deterrent (pine tar), and any broken square bales were replaced with the straw from broken bales remaining in the rooms. No additional litter management was performed. Mortality and culls were replaced with spare poults until d 11 when the brooder rings were removed, to allow for a more accurate prediction of final SD. Finally, if losses greater than 5% occurred, space was blocked in the last two weeks of the trial to ensure final SD was met.

3.3.3 Data collection

Health parameters. In both trials, 20 birds per replication were randomly selected and evaluated for gait score, foot pad lesion score, feather condition, and feather cleanliness on wk

12 and 16. Due to the presence of low levels of footpad lesions at 12 wk in trial 1, footpads were scored an additional time at wk 10 in trial 2. A total of 20 birds per replicate were evaluated at 10 wk of age for foot pad lesion score, feather condition, and feather cleanliness. Subjective gait scores were conducted by two independent scorers and birds were assigned a score of 0-5 using the gait scoring system from Vermette et al. (2016) which was adapted for turkeys from Garner et al. (2002) (Table 3.1). The two scores were then averaged for each bird. Foot pad lesion scoring was conducted by one individual by washing the right foot pad with a brush and scored on a scale of 0-4 using the system shown in Table 3.2 (Hocking et al., 2008). Feather condition was evaluated by one individual on four principle areas of the bird (breast, back, wings, and tail). Birds were feather condition scored using a graduated scale of 1-4 shown in Table 3.3 (adapted from Davami et al., 1987 and Sarica et al., 2008). Overall feather cleanliness was also scored using a scale of 1-4 shown in Table 3.4 by one observer, adapted from the broiler scoring system developed by Wilkins et al. (2003) on a scale of 1-8 (Forkman and Keeling, 2009).

The incidence and location of aggressive damage was recorded daily (back, wing, neck, head, and snood). Skin tears, though not necessarily due to aggression, were included as birds would typically start pecking at them once they occurred. Birds that were mildly affected were treated with a deterrent (pine tar) and the incidence recorded. Birds that were moderately impacted and deemed unsuitable to remain on trial, were weighed, removed from the trial, recorded as a cull bird and placed in a hospital pen. Birds that were severely impacted were euthanized, weighed, and recorded as cull birds. The incidence of aggressive damage was calculated for each 4 wk interval (0-4, 4-8, 8-12, and 12-16 wk) as well as overall (0-16 wk).

Heterophil/lymphocyte ratios (H/L ratios) were assessed as a measure of chronic stress. A total of 15 birds per replicate were randomly selected and blood was collected from the brachial vein into tubes containing EDTA using a vacutainer on wk 4, 8, 12, and 16. Blood smears were prepared the same day blood was collected. Slides were stained using PROTOCOL™ Hema 3™ (Fisher Scientific; Ottawa, Canada) and were stored in a slide box until read. H/L ratios were determined by counting the number of heterophils and lymphocytes within a field of view under 100X oil magnification until a total number of 100 cells was reached (microscope B-290TB; Optika©; Bergamo, Italy).

Crop/gizzard temperature, as an indicator of core body temperature, was evaluated in the second trial only, using a total of 3 birds per replicate. An iButton Thermochron™ temperature data logger (Maxim Integrated; San Jose, CA) was inserted into the crop of the bird at d 112 (iButtons typically travelled to the gizzard and remained there), and the temperature was recorded at 1 hour intervals for a period of 9 hours. Additionally, two IPTT-300 temperature transponders (BioMedic Data Systems, Inc; Seaford, DE) were implanted beneath the skin, with one on the mid-section of the left breast and one under the left wing in each of the 3 birds. Temperature readings from the transponders were taken hourly to pair with the iButton readings, with the objective of recording both surface and core body temperature.

Behaviour data. Video recordings were taken over a 24h time period for wk 12, 14, and 16 using one ceiling mounted infrared video camera system (Panasonic WV-CF224FX; Panasonic Corporation of North America, Secaucus, NJ). The cameras recorded to a computer system in continuous real-time mode. Field of view observations (with approximately ¼ of the room captured) were performed (Torrey et al., 2013) using instantaneous scan sampling of recorded video at 20 minute intervals and the number of birds within the field of view performing each behaviour was recorded (video playback via Genetec Omnicast Software, Genetec Inc., Montreal, Canada). Behaviours evaluated included feeding, drinking, locomotion, aggression, comfort, exploratory, maintenance, and feather pecking and are defined in Table 3.5.

3.3.4 Statistical analyses

Data were analyzed using SAS 9.4 (SAS®9.4, Cary, NC). The experiment (trial 1 and trial 2) was setup as a randomized complete block design. Data were checked for normality using Proc UNIVARIATE and log transformed (log +1) when necessary. Regression analyses were performed using Proc Reg (linear) and Proc RSReg (quadratic) to assess the relationship between treatment and dependent variables for gait score, footpad lesion score, feather condition, feather cleanliness, aggressive pecking, H/L ratio, core body temperature, and behaviour. Covariance was evaluated for core body temperature using room temperature as a covariate using Proc Mixed (SAS 9.4®, Cary, NC). Differences were considered significant if $P \leq 0.05$ and trends were noted when $P \leq 0.10$.

Table 3.1. Broiler gait scoring technique modified for turkeys (adapted from Garner et al., 2002; Vermette et al., 2016)

Gait score	Degree of impairment		Description
0	None	Original	Smooth, fluid locomotion. The foot is furled while raised.
		Modified	Straight legs.
1	Detectable, but unidentifiable abnormality	Original	The bird is unsteady, or wobbles when it walks. However, the problem leg is unclear, or cannot be identified in the first 20s of observation. The bird readily runs from the observer in the pen. The foot may remain flat when raised, but the rest of the stride is fluid and appears unimpaired.
		Modified	Gait appears unstable (shaky or stomping).
2	Identifiable abnormality that has little impact on overall function	Original	The leg producing the gait defect can be identified within 20 s of observation. If a problem leg is identified after 20 s of observed locomotor behaviour then the bird is classed as gait score 1. However, the defect seems to have only a minor impact on biological function. Thus the bird will run from the observer spontaneously or if touched or nudged with the padded stick. If the bird does not run at full speed, it runs, walks or remains standing for at least 15 s after the observer in the pen has ceased to move towards or nudge it. Birds in this, and previous, scores are often observed to scratch their face with their feet-again indicating little impact on function. (The most common abnormality in this score is for the bird to make short, quick, unsteady steps with one leg, where the foot remains flat during the step.)
3	Identifiable abnormality which impairs function	Original	Although the bird will move away from the observer when approached or touched, or nudged, it will not run, and squats within 15 s or less of the observer in the pen ceasing to approach or nudge it. If the bird squats after 15 s have elapsed it is classified as gait score 2.
4	Severe impairment of function, but still capable of walking	Original	The bird remains squatting when approached or nudged. This criterion is assessed by approaching the bird, and if it remains squatting, gently nudging or touching the animal for 5 s. Animals may appear to rise but still resting upon their hocks. Only rising to stand on both feet within 5 s of handling is counted—a bird which takes longer than 5 s to rise, or which does not rise at all is scored as 4, while a bird that rises in 5 s or less is counted as a 3 (or lower if its gait is good). Nevertheless, the bird can walk when picked up by the observer and placed in a standing position, but squats immediately following one or two steps. (Squatting often involves a characteristic ungainly backwards fall.)
		Modified	Bird requires wings for balance.
5	Complete lameness	Original	The bird cannot walk, and instead may shuffle along on its hocks. It may attempt to stand when approached but is unable to do so, and when placed on feet unable to complete a step with one or both legs.

Table 3.2. Footpad scoring technique (Hocking et al., 2008)

Score	Description of Footpad
0	No external signs of FPD. The skin of the foot pad feels soft to the touch and no swelling or necrosis is evident.
1	The pad feels harder and denser than a non-affected foot. The central part of the pad is raised, reticulate scales are separated and small black necrotic areas may be present.
2	Marked swelling of the foot pad. Reticulate scales are black, forming scale shaped necrotic areas. The scales around the outside of the black areas may have turned white. The area of necrosis is less than one quarter of the total area of the foot pad.
3	Swelling is evident and the total foot pad size is enlarged. Reticulate scales are pronounced, increased in number and separated from each other. The amount of necrosis extends to one half of the foot pad.
4	As score 3, but with more than half the foot pad covered by necrotic cells.

Table 3.3. Feather condition scoring technique adapted from Davami et al. (1987) and Sarica et al. (2008)

Score	Description of feather condition
1	No feather cover.
2	More than 50% of the plumage is missing.
3	Few or less than 50% of the plumage is missing.
4	Full, intact plumage.

Table 3.4. Feather cleanliness scoring (Forkman and Keeling (2009) as modified from Wilkins et al., 2003)

Score	Description of feather cleanliness
1	Very clean, >75% of the feathers/body are free from soiling.
2	Moderately clean, 50-75% of the feathers/body are free from soiling.
3	Moderately dirty, 25-50% of the feathers/body are free from soiling.
4	Very dirty, <25% of the feathers/body are free from soiling.

Table 3.5. Behavioural ethogram for turkey toms, as modified from Martrenchar et al., 1999 and Vermette et al., 2016

Behaviour	Description of Behaviour
Feeding	Standing or sitting with head in the feeder.
Drinking	Standing or sitting with head in the drinker.
Resting	Lying down, not performing any other behaviour. May or may not be sleeping.
Standing	Standing, not performing any other behaviour.
Walking	Bird walking or running. Must take 2 or more consecutive steps.
Strutting	Standing or walking slowly with feathers erect and breast thrust forward.
Fighting	Two or more individuals, where at least one bird is posturing with head back and breast thrust forward. May or may not include one individual running or jumping at the other.
Preening	Manipulating own feathers with the beak while standing or resting.
Stretching	Extension of the wings and/or legs.
Wing Flapping	Flapping both wings.
Dust Bathing	
Feather Ruffle	Full body shake while standing or resting.
Environmental Pecking	Pecking at walls, feeder tubes (not feed pan), drinker lines (away from the drinker cups), or litter while standing or resting.
Feather Pecking	Pecking at a pen mate's feathers while standing or resting. The pen mate typically does not move away.
Aggressive Pecking	Forceful pecking at a pen mate's head, body, or snood while standing or resting. The pen mate typically moves away.
Overall Disturbance	A bird in a laying posture opens its eyes, lifted its head or moved its body as a result of another bird walking in front of it, on top of it, touching it, or flapping near it.
Severe Disturbance	A bird in a lying posture stands up as a result of another bird walking in front of it, on top of it, or flapping near it.

3.4 Results

3.4.1 Mobility and footpad lesions

Stocking density did not affect bird mobility (assessed with the use of subjective gait scoring) at 12 wk of age (Table 3.6). At 16 wk however, mobility was poorer as SD increased, with mean gait scores of 1.23, 1.76, 1.66, and 1.89 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*=0.04, linear). The percentage of birds in each scoring division for footpad lesions, the average footpad lesion score, along with the frequency of footpad lesions are shown in Table 3.7. At 10 wk of age, there was a greater percentage of birds scoring a 0, indicative of no lesions, at lower SD (*P*=0.02, linear). There was also a greater percentage of birds scoring a 2, indicative of lesions covering less than 25% of the footpad, with increasing SD (*P*=0.01, linear). The overall footpad lesion scores at wk 10 increased in severity with increasing density, with mean lesion scores of 0.25, 0.55, 0.75, and 1.03 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*=0.01, linear). Footpad lesion frequency, expressed as the percentage of birds with a lesion of any size, also increased at 10 wk of age with the percentage of birds with lesions as follows 22.50, 42.50, 47.50, and 67.50 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*=0.02, linear). At 12 wk of age, there were no significant differences noted in birds housed at different densities for the frequency or severity of footpad lesion scores. Footpad lesion scores (0-4) also did not differ between treatments at 12 wk of age. At 16 wk of age, there was a greater percentage of birds scoring 4, indicative of a lesion greater than 50% of the footpad, as SD increased (*P*<0.01, linear). There was also a greater percentage of birds scoring a 3 as SD increased (*P*=0.05, linear). The severity (average footpad lesion score) increased in a linear manner as SD increased with mean values of 1.24, 1.20, 1.60, and 2.35 for treatments 30, 40, 50, and 60 kg/m^2 (*P*=0.02). Density treatment did not impact frequency of footpad lesions at 16 wk of age.

3.4.2 Feather condition and cleanliness

At 10 wk of age, feather condition was similar for toms across all treatments on the back or the wings but differences were noted on the tail and breast feathers (Table 3.8). Although the differences between treatments were not statistically significant, there was a tendency for improved wing feather condition scores of 3 (less than 50% of the plumage missing) and 4 (full intact plumage) at moderate densities of 40 and 50 kg/m^2 (*P*=0.08, quadratic). Tail feather condition decreased as SD increased with a higher percentage of birds scoring a 2 (greater than 50% of the plumage missing) at the higher SD (*P*=0.01, linear). Furthermore, there was a higher percentage of birds scoring a 3 for less than 50% of the plumage missing (*P*=0.02, linear) and 4 for full intact plumage at the lower SD (*P*<0.01, linear; trend quadratic *P*=0.07). Breast feather condition score demonstrated poorer feather condition with increasing SD, as a greater percentage of birds at low SD scored a 3 (less than 50% of the plumage missing) and a greater percentage of birds at high SD scored a 2 (over 50% of the plumage missing) (*P*=0.01 and *P*<0.01, respectively, linear). There was also a quadratic relationship with breast feather condition and increasing density, with a greater percentage of birds at the 30 and 60 kg/m^2 scoring a 1 (no feather cover), indicative of poor feather condition (*P*=0.03). Mean feather condition scores (total score out of 16) decreased as SD increased with mean scores of 13.65, 13.45, 12.70, and 12.43 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*<0.01, linear; Table 3.11).

At 12 wk of age, wing feather condition was not impacted by SD (Table 3.9). Back feather condition was moderately impacted by increasing SD, but only birds at 60 kg/m^2 demonstrated a decreased back feather condition with less than 50% of the plumage missing (score 3; *P*=0.02, quadratic). Tail feather score decreased with increasing density, with a higher percentage of birds scoring a 1 (no feather cover) or a 2 (more than 50% of the plumage missing) at higher densities (*P*=0.05, quadratic and *P*=0.03, linear, respectively). Further, birds at lower SD demonstrated better tail feather condition with a higher percentage of birds scoring a 3 (less than 50% of the plumage missing) or a 4 (full intact plumage) (*P*=0.02 and *P*=0.03, respectively, linear). Breast feather condition score followed a similar pattern, with a higher percentage of birds at low densities scoring a 3 for less than 50% of the plumage missing (*P*=0.03, linear) and tendency for a higher percentage of birds at high SD to score a 2 for greater than 50% of the plumage missing (*P*=0.07, linear). As a result, the mean feather condition score decreased as SD increased with mean values of 12.81, 12.65, 12.20, and 11.58 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*=0.02, linear; Table 3.11).

Feather condition at 16 wk of age was impacted on the back, tail, and breast, but turkey wing feather condition was similar for birds despite density changes (Table 3.10). Back feather condition decreased in a linear fashion as SD increased, with a higher percentage of birds with full intact plumage (score 4) at lower SD and a higher percentage of birds scoring a 3 (less than 50% of plumage missing) at higher SD (*P*=0.04). Tail feather condition was poorer as SD increased with a higher percentage of birds scoring a 1(no feather cover) and a 2 (greater than 50% of the plumage missing) at high SD (*P*<0.01 and *P*<0.01, respectively, linear). There was also a higher percentage of birds at low SD scoring a 3 (less than 50% of the plumage missing) and a 4 (full intact plumage), indicative of good feather condition (*P*<0.01, linear and *P*=0.03, quadratic). Breast feather condition also decreased as SD increased with a higher percentage of birds at high SD having no feather cover (score 1; *P*=0.01, quadratic) and a tendency for a higher percentage of birds at low SD to score a 3 (less than 50% of the plumage missing; *P*=0.07, quadratic). As a result the mean feather condition score decreased in a linear fashion with increasing density as shown in Table 3.11 (mean values of 12.84, 11.81, 11.56, and 11.18 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*<0.01)).

Feather cleanliness at 10 wk of age showed a linear relationship as SD increased with a higher percentage of birds scoring a 1 (very clean) at lower densities and a higher percentage of birds scoring a 2 (moderately clean) at higher densities (*P*=0.01 and *P*<0.01, respectively; Table 3.8). This is also reflected in the mean cleanliness values of 1.18, 1.28, 1.80, and 1.65 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*=0.01, linear; Table 3.11). At 12 wk of age, feather cleanliness decreased as SD increased with a higher percentage of birds scored as very clean (score 1) at lower densities (*P*<0.01, linear) and a higher percentage of birds scoring a 3 (moderately dirty) at higher SD (*P*<0.01, linear; Table 3.9). There was also a tendency for more birds at higher SD to be classified as very dirty (score 4; *P*=0.10, linear). Mean cleanliness scores at 12 wk of age also demonstrated that birds become dirtier as SD increases, with mean values of 1.48, 1.91, 2.20, and 2.36 for treatments 30, 40, 50, and 60 kg/m^2, respectively (*P*<0.01, linear; Table 3.11). Birds at 16 wk of age demonstrated poorer cleanliness scores as SD increased. Birds at lower densities were cleaner with a higher percentage of birds scoring a 1 for very clean (*P*<0.01, linear; Table 3.10). Birds at higher densities were dirtier with a higher percentage of birds scoring a 3 (moderately dirty; *P*<0.01, linear) and 4 (very dirty; *P*=0.02, linear). As a result, the mean cleanliness scores show dirtier birds as SD increases (1.45, 2.06, 2.37, and 2.73 for treatments 30, 40, 50, and 60 kg/m^2, respectively) with an increasing linear relationship as SD increases (*P*<0.01; Table 3.11).

3.4.3 Incidence of aggressive damage

Stocking density did not impact the total percentage of birds treated for aggressive damage (Table 3.12). Specifically, however, the incidence of skin tears demonstrated a quadratic relationship with SD, with a greater occurrence at 30 and 60 kg/m^2 (P=0.04; Table 3.12). There was also a tendency for the percentage of birds treated for aggressive damage to the head to be higher at both high and low SD (P=0.08, quadratic). The incidence of aggressive pecking was calculated for each 4 wk period and is shown in Table 3.12. There were no significant differences in the number of birds treated for aggressive pecking across treatments at 0-4, 8-12, 12-16, and 0-16 wk, however from 4-8 wk of age there was a quadratic relationship as SD increased, with birds at 30 and 60 kg/m^2 experiencing the highest incidence of aggressive damage (P=0.02). When culls related to aggressive damage were added, there was again a quadratic relationship for wk 4-8 with higher damage at low and high SD (P=0.04). Furthermore, the incidence of aggressive pecking was evaluated by location of damage for each 4 wk period (Table 3.13). At 0-4 wk, there was a quadratic relationship with birds at the 30 and 60 kg/m^2 treatments receiving the most damage to the tail area (P=0.04). At 4-8 wk, birds housed at 60 kg/m^2 experienced more aggressive damage to the neck (P=0.04, linear) and to the snood (P<0.01, quadratic) compared to other densities. There were no differences for wk 8-12. For wk 12-16 there was a quadratic effect on the number of skin tears with 30 and 60 kg/m^2 having the highest incidence (P=0.04).

3.4.4 Heterophil/lymphocyte ratio

The heterophil/lymphocyte ratio of toms increased linearly as SD increased at wk 4 (0.65, 0.77, 0.75, and 0.79 for treatments 30, 40, 50, and 60 kg/m^2, respectively), (P=0.01; Table 3.14). For wk 12, there was a tendency for a linear relationship with increasing H/L ratios as SD increased (0.93, 0.89, 1.10, and 1.01 for treatments 30, 40, 50, and 60 kg/m^2, respectively) with a P-value of 0.07. At 16 wk of age, treatment had no impact on bird H/L ratio.

3.4.5 Core body temperature

Room temperature decreased linearly as SD increased as shown in Table 3.15 (9.92, 9.43, 9.96, and 8.95°C for treatments 30, 40, 50, and 60 kg/m^2, respectively; P=0.03). This likely corresponds with increases in ventilation rates at higher SD to maintain equal air quality. The subcutaneous temperature transponder located on the breast demonstrated a tendency for body temperature to decrease as SD increased (P=0.08, linear). The wing temperature transponder demonstrated a significant linear relationship between body temperature and increasing SD (P<0.01), with body temperature decreasing as SD increased. Core body temperature (crop/gizzard), measured with the use of an ingested iButton data, also demonstrated decreasing core body temperature with increasing density (P=0.03, linear).

When relating body temperature to increasing SD using room temperature as a covariate (Table 3.15), differences in the subcutaneous wing transponder and iButton core body temperature remained significant (P<0.01 and P=0.03, respectively) with body temperature decreasing as SD increased. The subcutaneous breast transponder showed no significant differences in body temperature in relation to SD.

3.4.6 Behavioural observations

At 12 wk of age, SD impacted the percentage of toms standing and walking, as well as the incidence of total disturbances (Table 3.16). The percentage of birds standing demonstrated a quadratic relationship with increasing SD (16.84, 15.04, 14.54, and 19.54 for treatments 30, 40, 50, and 60 kg/m^2, respectively; P=0.02). The percentage of birds walking decreased linearly with increasing SD, as more birds were observed walking at lower densities (P=0.03). Additionally, the percentage of birds experiencing disturbances demonstrated a decreasing linear relationship with increasing density (0.27, 0.16, 0.11, and 0.05 for treatments 30, 40, 50, and 60 kg/m^2, respectively; P=0.01).

At 14 wk of age, SD affected the percentage of birds seen resting, walking, preening, performing comfort behaviours and strutting (Table 3.17). The percentage of birds resting increased with increasing SD with 53.98, 60.64, 68.21, and 64.34% of birds resting for 30, 40, 50, and 60 kg/m^2, respectively (P=0.02, linear; trend P=0.07, quadratic). Walking behaviour demonstrated a decreasing linear relationship with increasing SD (P=0.04). Similarly, the percentage of birds strutting decreased linearly with increasing SD (0.26, 0.11, 0.10, and 0% for 30, 40, 50, and 60 kg/m^2, respectively; P=0.01). Finally, the percentage of birds preening and performing comfort behaviours both increased linearly in relation to increasing SD (P=0.01 and P=0.03, respectively).

At wk 16, SD affected the percentage of birds resting, standing, walking, feeding, preening, and engaging in aggressive pecking (Table 3.18). The percentage of birds resting (45.88, 62.01, 68.14, and 59.05%; $P<0.01$) and standing (22.99, 18.12, 17.20, and 24.54%; $P=0.01$) demonstrated quadratic relationships as SD increased for treatments 30, 40, 50 and 60 kg/m^2, respectively. Both walking and feeding behaviour showed a decreasing quadratic relationship with increasing SD ($P=0.02$ and $P=0.02$, respectively). There was also a decreasing quadratic effect on the percentage of birds drinking with increasing SD ($P=0.05$). The percentage of birds that were preening increased linearly as SD increased (2.73, 3.82, 4.08, and 4.02% for treatments 30, 40, 50, and 60 kg/m^2, respectively; $P=0.02$). Finally, the percentage of birds engaging in aggressive pecking increased linearly with increasing SD (0.20, 0.10, 0.14, and 0.27% for treatments 30, 40, 50, and 60 kg/m^2, respectively; $P=0.04$).

Table 3.6. Effect of estimated final stocking density on turkey tom gait score percentage in each scoring category and average score (scale 0-5[1]) at 12 and 16 weeks of age.

% In category	Estimated final stocking density (kg/m²)				SEM[2]	P-value (Linear)	P-value (Quadratic)	Regression Equation[3]
	30	40	50	60				
Gait score wk 12								
0	35.63	39.38	33.13	28.13	3.422	0.37	0.54	-
1	32.50	31.88	35.00	41.25	2.971	0.28	0.58	-
2	25.63	23.75	21.88	25.00	2.670	0.88	0.67	-
3	3.75	5.00	10.00	5.63	1.461	0.44	0.36	-
4	2.50	0	0	0	0.625	0.19	0.32	-
5	0	0	0	0	-	-	-	-
Average score	1.05	0.94	1.09	1.08	0.043	0.55	0.59	-
Gait score wk 16								
0	20.63	4.38	10.63	6.25	2.533	0.11	0.22	-
1	38.13	31.25	25.00	23.13	3.502	0.10	0.72	-
2	38.75	52.50	54.38	51.88	3.502	0.20	0.25	-
3	2.50	8.13	7.50	12.50	2.321	0.16	0.95	-
4	0	3.75	2.50	6.25	1.281	0.13	1.00	-
5	0	0	0	0	-	-	-	-
Average score	1.23	1.76	1.66	1.89	0.106	0.04	0.45	Y=0.02x+0.07

[1]Score of 0= no impairment and 5=complete lameness (adapted from Garner et al., 2002 by Vermette et al., 2016).

[2] Standard error of the mean.

[3]Regression considered significant if $P \leq 0.05$.

Table 3.7. Effect of estimated final stocking density on turkey tom footpad lesion score expressed as the percentage in each scoring category (scale 0-4[1]), average footpads score, and lesion frequency (%) at 12 and 16 weeks of age

% In category	n	Estimated final stocking density (kg/m^2)				SEM[2]	P-value (Linear)	P-value (Quadratic)	Regression Equation[3]
		30	40	50	60				
Footpad score wk 10[4]									
0	2	77.50	57.50	52.50	32.50	7.320	0.02	1.00	Y=-0.06x+5.45
1	2	20.00	30.00	20.00	32.50	4.476	0.53	0.91	-
2	2	2.50	12.50	27.50	35.00	5.782	0.01	0.88	Y=0.05x-1.44
3	2	0	0	0	0	0	-	-	-
4	2	0	0	0	0	0	-	-	-
Average Score	2	0.25	0.55	0.75	1.03	0.124	0.01	0.94	Y=0.03x-0.49
Frequency[5]	2	22.50	42.50	47.50	67.50	7.319	0.02	1.00	Y=1.40x-18.00
Foot pad score wk12									
0	4	40.00	31.25	23.75	22.5	5.825	0.26	0.76	-
1	4	20.00	23.75	13.75	18.75	3.235	0.65	0.93	-
2	4	30.00	33.75	48.75	33.75	4.781	0.56	0.36	-
3	4	7.50	10.00	7.50	20.00	3.400	0.26	0.48	-
4	4	2.50	1.25	6.25	5.00	1.407	0.34	1.00	-
Average Score	4	1.13	1.26	1.59	1.66	0.176	0.23	0.93	-
Frequency	4	60.00	68.75	76.25	77.50	5.825	0.26	0.76	-
Foot pad score wk 16									
0	4	32.50	38.75	33.75	15.00	4.743	0.18	0.18	-
1	4	21.25	15.00	12.50	13.75	2.230	0.22	0.41	-
2	4	36.25	36.25	25.00	21.25	4.170	0.14	0.82	-
3	4	10.00	7.50	17.50	21.25	2.550	0.05	0.52	-
4	4	0	2.50	11.25	28.75	3.896	<0.01	0.20	Y=0.95x-32.13
Average Score	4	1.24	1.20	1.60	2.35	0.189	0.02	0.23	Y=0.04x-0.09
Frequency	4	67.50	61.25	66.25	85.00	4.743	0.18	0.18	-

[1]Score 0= no external signs of a lesion, Score 4= greater than 50% of the footpad covered with necrotic cells (Hocking et al., 2008).
[2] Standard error of the mean.
[3]Regression considered significant if $P \leq 0.05$.
[4] Week 10 footpad score for trial 2 only.
[5]The percentage of birds scoring 1-4, exhibiting visual signs of a footpad lesion.

Table 3.8. Effect of estimated final stocking density on turkey tom feather condition score (scale 1-4[1]) and feather cleanliness score (scale 1-4[2]) at 10 weeks of age[3]

% In category	n	Estimated final stocking density (kg/m^2) 30	40	50	60	SEM[4]	P-value (Linear)	P-value (Quadratic)	Regression Equation[5]
Back feather score									
1	2	0	0	0	0	0	-	-	-
2	2	0	0	0	0	0	-	-	-
3	2	0	0	0	0	0	-	-	-
4	2	100.00	100.00	100.00	100.00	0	-	-	-
Wing feather score									
1	2	0	0	0	0	0	-	-	-
2	2	0	0	0	0	0	-	-	-
3	2	7.50	0	5.00	10.00	1.752	0.47	0.08	-
4	2	92.50	100.00	95.00	90.00	1.752	0.47	0.08	-
Tail feather score									
1	2	0	0	0	2.50	0.625	0.20	0.33	-
2	2	2.50	22.50	55.00	50.00	8.660	0.01	0.23	Y=1.75x-46.25
3	2	72.50	67.50	45.00	47.50	5.256	0.02	0.64	Y=-0.98x+102.00
4	2	25.00	10.00	0	0	4.092	<0.01	0.07	Y=-0.85x+47.00
Breast feather score									
1	2	5.00	0	2.50	7.50	1.250	0.41	0.03	Y=0.03x^2-2.15x+46.75
2	2	40.00	45.00	65.00	77.50	6.542	0.01	0.65	Y=1.33x-2.75
3	2	55.00	52.50	32.50	15.00	6.797	<0.01	0.34	Y=-1.40x+101.75
4	2	0	2.50	0	0	0.625	0.69	0.40	-
Cleanliness score									
1	2	82.50	72.50	25.00	35.00	9.484	0.01	0.41	Y=-1.90x+139.25
2	2	17.50	27.50	70.00	65.00	8.964	<0.01	0.48	Y=1.85x-38.25
3	2	0	0	5.00	0	0.818	0.54	0.16	-
4	2	0	0	0	0	0	-	-	-

[1]Score of 1=no feather cover, 2= greater than 50% of the plumage is missing, 3= less than 50% of the plumage is missing, and 4=full intact plumage (Davami et al., 1987 and Sarica et al., 2008); [2] Score of 1= very clean, 2= moderately clean, 3=moderately dirty, and 4= very dirty (Forkman and Keeling (2009) as modified from Wilkins et al., 2003); [3]Week 10 feather score for trial 2 only. [4]Standard error of the mean; [5]Regression considered significant if P≤0.05.

Table 3.9. Effect of estimated final stocking density on turkey tom feather condition score (scale 1-4[1]) and feather cleanliness score (scale 1-4[2]) at 12 weeks of age

% In category	Estimated final stocking density (kg/m^2) 30	40	50	60	SEM[3]	P-value (Linear)	P-value (Quadratic)	Regression Equation[4]
Back feather score								
1	0	0	0	0	0	-	-	-
2	0	0	0	1.25	0.313	0.19	0.32	-
3	0	0	0	8.75	1.205	0.01	0.02	$Y=0.02x^2-1.71x+31.94$
4	100	100	100	90.00	1.443	0.01	0.03	$Y=-0.03x^2+1.95x+63.50$
Wing feather score								
1	0	0	0	0	0	-	-	-
2	0	0	3.75	0	0.680	0.56	0.19	-
3	43.75	31.25	42.50	51.25	7.486	0.63	0.51	-
4	56.25	68.75	53.75	48.75	7.717	0.60	0.60	-
Tail feather score								
1	0	0	0	11.25	1.706	0.02	0.05	$Y=0.03x^2-2.19x+41.06$
2	21.25	26.25	47.50	53.75	6.258	0.03	0.96	$Y=1.19x-16.25$
3	66.25	67.50	51.25	33.75	5.800	0.02	0.36	$Y=-1.14x+105.88$
4	12.50	6.25	1.25	1.25	2.014	0.03	0.39	$Y=-0.39x+22.75$
Breast feather score								
1	3.75	8.75	7.50	13.75	2.766	0.26	0.91	-
2	60.00	66.25	68.75	77.50	3.412	0.07	0.85	-
3	35.00	25.00	23.75	8.75	4.205	0.03	0.74	$Y=-0.80x+59.13$
4	1.25	0	0	0	0.313	0.19	0.32	-
Cleanliness score								
1	53.75	23.75	13.75	10.00	5.764	<0.01	0.12	$Y=-1.41x+88.88$
2	45.00	62.50	53.75	48.75	3.846	0.95	0.17	-
3	1.25	12.50	31.25	36.25	5.031	<0.01	0.69	$Y=1.24x-35.38$
4	0	1.25	1.25	5.00	1.008	0.10	0.53	-

[1]Score of 1=no feather cover, 2= greater than 50% of the plumage is missing, 3= less than 50% of the plumage is missing, and 4=full intact plumage (Davami et al., 1987 and Sarica et al., 2008); [2] Score of 1= very clean, 2= moderately clean, 3=moderately dirty, and 4= very dirty (Forkman and Keeling (2009) as modified from Wilkins et al., 2003); [3]Standard error of the mean; [4]Regression considered significant if $P \leq 0.05$.

Table 3.10. Effect of estimated final stocking density on turkey tom feather condition score (scale 1-4[1]) and feather cleanliness score (scale 1-4[2]) at 16 weeks of age

% In category	Estimated final stocking density (kg/m^2)				SEM[3]	P-value (Linear)	P-value (Quadratic)	Regression Equation[4]
	30	40	50	60				
Back feather score								
1	0	0	0	0	0	-	-	-
2	0	0	0	0	0	-	-	-
3	2.50	3.75	6.25	15.00	2.183	0.04	0.35	Y=0.40x-11.13
4	97.50	96.25	93.75	85.00	2.183	0.04	0.35	Y=-0.40x+111.13
Wing feather score								
1	0	0	0	0	0	-	-	-
2	0	0	1.25	0	0.313	0.67	0.35	-
3	17.50	33.75	38.75	48.75	8.055	0.18	0.85	-
4	82.50	66.25	60.00	51.25	8.178	0.18	0.82	-
Tail feather score								
1	0	10.00	11.25	20.00	2.478	<0.01	0.87	Y=0.61x-17.25
2	20.00	42.50	53.75	65.00	5.562	<0.01	0.47	Y=1.46x-20.50
3	66.25	47.50	35.00	15.00	6.059	<0.01	0.94	Y=-1.66x+115.75
4	13.75	0	0	0	1.975	0.01	0.03	$Y=0.03x^2-3.51x+87.31$
Breast feather score								
1	6.25	27.50	25.00	22.50	2.794	0.06	0.01	$Y=-0.06x^2+5.81x-113.31$
2	77.50	63.75	70.00	68.75	2.236	0.33	0.17	-
3	16.25	8.75	5.00	8.75	1.675	0.08	0.07	-
4	0	0	0	0	0	-	-	-
Cleanliness score								
1	56.25	18.75	11.25	0	6.467	<0.01	0.11	Y=-1.76x+100.88
2	42.50	58.75	46.25	41.25	5.438	0.75	0.36	-
3	1.25	20.00	36.25	45.00	6.156	<0.01	0.61	Y=1.48x-40.75
4	0	2.50	6.25	13.75	2.276	0.02	0.54	Y=0.45x-14.63

[1]Score of 1=no feather cover, 2= greater than 50% of the plumage is missing, 3= less than 50% of the plumage is missing, and 4=full intact plumage (Davami et al., 1987 and Sarica et al., 2008); [2] Score of 1= very clean, 2= moderately clean, 3=moderately dirty, and 4= very dirty (Forkman and Keeling (2009) as modified from Wilkins et al., 2003); [3]Standard error of the mean; [4]Regression considered significant if $P \leq 0.05$.

Table 3.11. Effect of estimated final stocking density on turkey tom overall feather condition (scale 1-4[1]) and cleanliness scores (scale 1-4[2]) at 10, 12, and 16 weeks of age

Wk	n	Estimated final stocking density (kg/m^2)				SEM[3]	P-value (Linear)	P-value (Quadratic)	Regression Equation[4]
		30	40	50	60				
Average feather condition score[5]									
10	2	13.65	13.45	12.70	12.43	0.203	<0.01	0.85	Y=-0.04x+15.05
12	4	12.81	12.65	12.20	11.58	0.214	0.02	0.55	Y=-0.04x+14.18
16	4	12.84	11.81	11.56	11.18	0.186	0.01	0.16	Y=-0.05x+14.20
Average feather cleanliness score									
10	2	1.18	1.28	1.80	1.65	0.100	0.01	0.36	Y=0.02x+0.60
12	4	1.48	1.91	2.20	2.36	0.115	<0.01	0.41	Y=0.03x+0.66
16	4	1.45	2.06	2.37	2.73	0.156	<0.01	0.54	Y=0.04x+0.29

[1]Score of 1=no feather cover, 2= greater than 50% of the plumage is missing, 3= less than 50% of the plumage is missing, and 4=full intact plumage (Davami et al., 1987 and Sarica et al., 2008); [2] Score of 1= very clean, 2= moderately clean, 3=moderately dirty, and 4= very dirty (Forkman and Keeling (2009) as modified from Wilkins et al., 2003); [3]Standard error of the mean; [4] Regression considered significant if P≤0.05; [5]Sum of four parts: back, wings, tail, breast, scored on a scale of 1-4.

Table 3.12. Effect of estimated final stocking density on the incidence and location of aggressive damage and skin tears (% of birds placed) determined at 16 weeks of age

Location	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
% of birds treated with a deterrent by location									
Tail	2	5.74	4.97	5.81	8.26	0.777	0.25	0.41	-
Wing	2	3.28	3.11	2.27	2.97	0.560	0.97	0.88	-
Back	2	0.82	0	0	0	0.205	0.20	0.33	-
Neck	2	0.82	0.31	1.26	1.27	0.336	0.44	0.62	-
Head	2	0.41	0.31	0	1.91	0.319	0.21	0.08	-
Snood	2	0	0.31	0	1.06	0.178	0.07	0.26	-
Skin tear	2	0.41	0	0	0.64	0.135	0.58	0.04	$Y=0.26e^{-2}x^2-0.23x+4.92$
Total	2	11.48	9.01	9.34	16.10	1.415	0.48	0.12	-
% of birds treated with a deterrent by time period									
Wk 0-4	2	0.41	0.31	0.25	1.48	0.223	0.16	0.13	-
Wk 4-8	2	3.28	1.86	2.02	6.14	0.705	0.32	0.02	$Y=0.01x^2-1.16x+25.70$
Wk 8-12	2	3.69	4.35	2.53	4.24	0.501	0.83	0.36	-
Wk 12-16	2	3.69	2.48	4.55	4.03	0.688	0.70	0.55	-
Wk 0-16	2	11.48	9.01	9.34	16.10	1.415	0.48	0.12	-
% of birds treated with a deterrent plus all culls related to aggressive damage by time period									
Wk 0-4	2	0.41	0.31	0.25	1.48	0.223	0.16	0.13	-
Wk 4-8	2	3.28	2.48	2.27	8.90	1.085	0.19	0.04	$Y=0.02x^2-1.50x+31.99$
Wk 8-12	2	6.15	5.59	4.80	6.14	0.792	0.85	0.64	-
Wk 12-16	2	8.20	7.45	6.82	7.63	0.718	0.72	0.56	-
Wk 0-16	2	18.03	15.84	14.14	24.15	1.963	0.60	0.18	-

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

Table 3.13. Effect of estimated final stocking density on the incidence of aggressive damage and skin tears (% of birds placed) by location of damage from 0-4, 4-8, 8-12, 12-16, and 0-16 weeks of age

% tarred in each location	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
Wk 0-4									
Tail	2	0.41	0	0.25	1.27	0.202	0.15	0.04	$Y=0.004x^2-0.29x+5.99$
Wing	2	0	0.31	0	0	0.078	0.69	0.40	-
Back	2	0	0	0	0	0	-	-	-
Neck	2	0	0	0	0	0	-	-	-
Head	2	0	0	0	0.21	0.053	0.20	0.33	-
Snood	2	0	0	0	0	0	-	-	-
Skin tear	2	0	0	0	0	0	-	-	-
Wk 4-8									
Tail	2	1.64	0.62	1.52	2.54	0.413	0.41	0.27	-
Wing	2	1.64	0.93	0	0.42	0.399	0.29	0.64	-
Back	2	0	0	0	0	0	-	-	-
Neck	2	0	0	0.51	0.85	0.184	0.04	0.57	$Y=0.03x-1.03$
Head	2	0	0.31	0	1.48	0.311	0.13	0.35	-
Snood	2	0	0	0	0.85	0.139	0.02	<0.01	$Y=0.002x^2-0.17x+3.09$
Skin tear	2	0	0	0	0	0	-	-	-
Wk 8-12									
Tail	2	2.05	3.11	1.52	2.54	0.440	0.90	0.99	-
Wing	2	1.23	1.24	0.76	1.48	0.215	0.95	0.47	-
Back	2	0.41	0	0	0	0.102	0.20	0.33	-
Neck	2	0	0	0.25	0	0.063	0.69	0.40	-
Head	2	0.41	0	0	0.21	0.108	0.65	0.19	-
Snood	2	0	0	0	0.21	0.053	0.20	0.33	-
Skin tear	2	0	0	0	0	0	-	-	
Wk 12-16									
Tail	2	1.64	1.24	2.53	1.91	0.358	0.56	0.85	-
Wing	2	0.41	0.62	1.52	1.06	0.287	0.26	0.57	-
Back	2	0.41	0	0	0	0.102	0.20	0.33	-
Neck	2	0.82	0.31	0.51	0.42	0.204	0.82	0.69	-
Head	2	0	0	0	0	0	-	-	-
Snood	2	0	0.31	0	0	0.078	0.69	0.40	-
Skin tear	2	0.41	0	0	0.64	0.135	0.58	0.04	$Y=0.26e^{-2}x^2-0.23x+4.92$

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.

Table 3.14. Effect of estimated final stocking density on turkey tom heterophil/lymphocyte ratio at 4, 12, and 16 weeks of age

Age	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value	P-value	Regression Equation[2]
(wk)		30	40	50	60		(Linear)	(Quadratic)	
4	4	0.65	0.77	0.75	0.79	0.018	0.01	0.24	$Y=0.40e^{-2}x+0.56$
12	4	0.93	0.89	1.10	1.01	0.028	0.07	0.65	-
16	4	0.86	0.76	0.85	0.90	0.027	0.40	0.16	-

[1]Standard error of the mean.

[2]Regression considered significant if $P \leq 0.05$.

Table 3.15. Effect of estimated final stocking density on turkey tom body temperature at 16 weeks of age

Location	Estimated final stocking density (kg/m^2)				P-value (COV)[3]	SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
	30	40	50	60					
Breast transponder (subcutaneous)	38.08	38.29	38.06	37.76	0.12	0.077	0.08	0.10	-
Wing transponder (subcutaneous)	39.91	39.64	39.10	39.09	<0.01	0.056	<0.01	0.18	$Y=-0.03x+40.78$
iButton (core body temperature)	41.12	41.08	41.00	40.85	0.03	0.043	0.03	0.51	$Y=-0.86e^{-2}x+41.40$
Room temperature	9.92	9.43	9.96	8.95	-	0.124	0.03	0.29	$Y=-0.02x+10.64$

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.
[3]Covariance test using Proc Mixed model var=trt roomtemp.

Table 3.16. Effect of estimated final stocking density on percentage of turkey toms performing various behaviours (% of birds within the field of view) at 12 weeks of age

Behaviour	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value	P-value	Regression Equation[2]
		30	40	50	60		(Linear)	(Quadratic)	
Resting	2	60.56	66.06	67.53	63.18	1.980	0.54	0.32	-
Standing	2	16.84	15.04	14.54	19.54	1.063	0.10	0.02	$Y=0.02x^2-1.45x+45.37$
Walking	2	5.21	4.32	2.67	2.64	0.591	0.03	0.41	$Y=-0.09x+7.93$
Feeding	2	6.48	5.00	5.35	5.55	0.684	0.33	0.58	-
Drinking	2	2.63	1.87	2.01	2.14	0.522	0.42	0.97	-
Preening	2	4.57	4.65	5.06	4.60	0.267	0.15	0.96	-
Comfort[3]	2	0.47	0.34	0.44	0.19	0.056	0.80	0.37	-
Strutting	2	0	0.06	0	0.14	0.026	0.20	0.61	-
Fighting	2	0	0	0.08	0	0.019	0.69	0.40	-
Posturing	2	0	0.04	0	0.03	0.012	0.60	0.93	-
Environmental pecking	2	2.22	1.58	1.18	1.33	0.192	0.72	0.14	-
Feather pecking	2	0.40	0.72	0.73	0.50	0.085	0.29	0.16	-
Aggressive pecking	2	0.34	0.13	0.30	0.12	0.045	0.64	0.97	-
Total disturbance[4]	2	0.27	0.16	0.11	0.05	0.035	0.01	0.81	$Y=-0.01x+0.46$

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.
[3]Comfort: stretching, wing flapping, dustbathing, head scratching, and feather ruffling.
[4]Total disturbance: moderate disturbances and severe disturbances.

Table 3.17. Effect of estimated final stocking density on percentage of turkey toms performing various behaviours (% of birds within the field of view) at 14 weeks of age

Behaviour	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value	P-value	Regression
		30	40	50	60		(Linear)	(Quadratic)	Equation[2]
Resting	4	53.98	60.64	68.21	64.34	1.880	0.02	0.07	$Y=0.39x+44.41$
Standing	4	22.22	19.36	17.52	18.76	0.787	0.91	0.76	-
Walking	4	5.86	4.59	2.54	3.21	0.423	0.04	0.24	$Y=-0.10x+8.56$
Feeding	4	7.55	5.15	2.63	4.09	0.590	0.09	0.08	-
Drinking	4	4.50	2.43	1.92	2.73	0.539	0.94	0.28	-
Preening	4	3.02	4.66	4.60	4.74	0.288	0.01	0.15	$Y=0.05x+1.96$
Comfort[3]	4	0.12	0.40	0.22	0.37	0.045	0.03	0.30	$Y=0.57e^{-2}x+0.02$
Strutting	4	0.26	0.11	0.10	0	0.033	0.01	0.98	$Y=-0.81e^{-2}x+0.48$
Fighting	4	0	0	0.02	0.03	0.009	0.17	0.83	-
Posturing	4	0.06	0.04	0	0.08	0.018	0.79	0.14	-
Environmental pecking	4	1.44	1.53	1.18	0.99	0.154	0.90	0.42	-
Feather pecking	4	0.65	0.62	0.81	0.41	0.080	0.88	0.15	-
Aggressive pecking	4	0.34	0.23	0.09	0.11	0.044	0.06	0.58	-
Total disurbance[4]	4	0.05	0.17	0.15	0.18	0.030	0.06	0.60	-

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.
[3]Comfort: stretching, wing flapping, dustbathing, head scratching, and feather ruffling.
[4]Total disturbance: moderate disturbances and severe disturbances.

Table 3.18. Effect of estimated final stocking density on percentage of turkey toms performing various behaviours (% of birds within the field of view) at 16 weeks of age

Behaviour	n	Estimated final stocking density (kg/m^2)				SEM[1]	P-value (Linear)	P-value (Quadratic)	Regression Equation[2]
		30	40	50	60				
Resting	4	45.88	62.01	68.14	59.05	2.509	0.01	<0.01	$Y=-0.06x^2+6.11x-81.23$
Standing	4	22.99	18.12	17.20	24.54	1.330	0.22	0.01	$Y=0.03x^2-2.70x+76.77$
Walking	4	6.92	3.94	2.33	2.97	0.527	0.01	0.02	$Y=0.01x^2-0.94x+27.18$
Feeding	4	9.06	4.11	2.78	3.36	0.784	0.03	0.02	$Y=0.01x^2-1.43x+39.49$
Drinking	4	6.08	3.12	2.04	2.93	0.531	0.14	0.05	$Y=0.01x^2-0.97x+26.58$
Preening	4	2.73	3.82	4.08	4.02	0.363	0.02	0.34	$Y=0.04x+1.72$
Comfort[3]	4	0.34	0.45	0.46	0.19	0.077	0.94	0.17	-
Strutting	4	1.73	0.99	0.40	0.58	0.228	0.14	0.42	-
Fighting	4	0	0.03	0	0	0.008	0.73	0.37	-
Posturing	4	0.30	0.08	0	0.07	0.049	0.22	0.14	-
Environmental pecking	4	2.54	1.81	1.37	0.83	0.302	0.30	0.55	-
Feather pecking	4	0.96	1.02	0.61	0.82	0.157	0.97	0.88	-
Aggressive pecking	4	0.20	0.10	0.14	0.27	0.043	0.04	0.20	$Y=0.19e^{-2}x+0.09$
Total disturbance[4]	4	0.26	0.42	0.49	0.40	0.087	0.20	0.44	-

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.
[3]Comfort: stretching, wing flapping, dustbathing, head scratching, and feather ruffling.
[4]Total disturbance: moderate disturbances and severe disturbances.

3.5 Discussion and Conclusions

While bird health and welfare are important, many of the previous studies focused on bird performance, resulting in little information available on bird wellbeing with respect to SD of heavy toms. Health and wellbeing of birds can be difficult to evaluate, as a result multiple parameters have been evaluated in combination in the current study to assess the effects of SD on turkey toms. Some of the health and welfare parameters evaluated in previous studies include feather cover, footpad lesions, mobility, heterophil/lymphocyte ratio, and behaviour. The current stocking density recommendations in Canada vary based on bird body weight and additional environmental and management conditions that must be met by the producer in order to house at the higher SD (50-60 kg/m^2 for birds weighing 10.8-13.3 kg to 55-65 kg/m^2 for birds weighing above 13.3 kg) (NFACC, 2016). This is important as it relates to the desired end use of the bird (whole bird vs further processing) and therefore it is important to consider the impact of SD on birds marketed at both lighter and heavier weights.

Mobility is concerning from a bird health and welfare standpoint, with poor mobility impacting the bird's ability to access food and water, escape aggressive pen mates, and potentially resulting in pain (Duncan et al., 1991; Kestin et al., 1992; Classen et al., 1994; Mc Geown et al., 1999). Poor mobility and decreased activity levels have also been related to poorer skeletal health in turkeys reared at high SD (Jankowski et al., 2015). Bird mobility (subjective gait score) demonstrated no differences at 12 wk of age, while at wk 16 bird mobility was significantly poorer with increasing SD. These findings are similar to the findings of Martrenchar et al. (1999) who observed that gait score was poorer in 12 wk hens and 16 wk toms housed at high SD. It has been hypothesized that the decrease in mobility seen with increasing SD may be a result of reductions in bird activity due to space (Martrenchar et al., 1999). This has also been suggested in broiler chickens, where gait score was negatively impacted by increasing SD and the authors noted that bird movement was restricted (Sørenson et al., 2000). Decreases in mobility due to increasing SD may pose a risk to the wellbeing of the bird. Birds that have difficulty walking may take longer to reach feed and water or avoid getting up to access feed, resulting in reductions in body weight and in severe instances dehydration and culls (Mc Geown et al., 1999). In addition, Classen et al. (1994) suggested that small pen size may result in weaker birds being cornered and subjected to aggressive damage by larger pen mates. This could also apply to high SD, where birds may not have the space to escape aggressive pen mates.

Poor gait scores may also indicate that the bird is experiencing pain. Footpad lesions may be painful to the bird and have been shown to result in alterations in gait (Martland, 1984; Weber Wyneken et al., 2015). In the present study, footpad lesions increased in severity with increasing SD at both 10 and 16 wk of age. Similar results have been seen in turkeys previously, with a higher incidence of foot pad lesions present at higher SD in 12 wk old hens and 16 wk old toms at slaughter (Martrenchar et al., 1999). These findings suggest that the decline in mobility seen with increasing SD may be partially due to pain associated with footpad lesions. Increases in the frequency of foot pad lesions have been closely linked to increases in litter moisture (Martland, 1984; Martrenchar et al., 1999; Hocking and Wu, 2013; Sinclair et al., 2015). Litter moisture has often been associated with increasing SD likely as a result of increased excreta output, but also due to reduced exposure of the litter to the air as it is more densely populated with birds (Proudfoot et al., 1979a; Noll et al., 1991; Martrenchar et al., 1997; Martrenchar et al., 1999).

Another factor contributing to bird health and welfare is feather condition. Feather cover is important as it offers the bird protection from scratches and other injuries and it acts as an insulator for thermoregulation, improving feed efficiency (Leeson and Morrison, 1978; Deschutter and Leeson, 1986). In addition, poor feather condition may indicate damaged feathers or missing feathers due to feather pecking. The removal of feathers has been associated with pain (Gentle and Hunter, 1990), indicating that more aggressive forms of feather pecking may be detrimental to bird health and wellbeing. Feather condition was consistently poorer at high SD for toms at 10, 12, and 16 wk of age. Although feather condition is not frequently evaluated in relation to turkey SD, these findings are consistent with those seen in 14 wk old turkeys housed at high SD, where poorer feather condition was seen with increasing density (Coleman and Leighton, 1969). When feather condition score is examined on different sections of the body, including the back, wings, tail, and breast, the data further demonstrated which areas are most impacted. The condition of the wing feathers were not affected at 10, 12, or 16 wk suggesting that density may not have an impact on condition of the wing feathers. The breast feather score was variable in relation to SD, with the overall pattern showing poorer breast feather condition at high SD. Although turkeys do not typically have a lot of feathering on the breast, poorer feathering at high densities could be attributed to increased contact with wet litter (Thomas et al., 2004). The back feathers were not impacted at 10 wk, however toms had poorer condition at 12 and 16 wk at high SD with the damage being more severe in the later. The back feathers may be impacted at older ages, as toms become limited by space and may walk over top of other birds. Tail feathers show decreased condition with increased SD at 10, 12, and 16 wk of age. This could be due to space restrictions developing as birds grow, with tail feathers being the most severely impacted as they likely experience more friction as birds are moving past each other at higher SD. If this was the case, it would be expected that the condition of the wings would also be poorer, however this was not seen in the present study. The tail feathers are also likely to be stepped on more frequently as birds are resting due to the space restrictions seen with increasing SD. Another factor impacting tail condition could be feather pecking, although not seen statistically, the incidence of aggressive damage to the tail occurred at the highest frequency in the 60 kg/m^2 treatment. A study conducted on laying hens demonstrated similar effects with increasing density resulting in decreases in feather condition for the neck, chest, tail, back, and wings (Sarica et al., 2008). The authors suggested that the hens at low densities did not exhibit as much feather pecking as they had a greater space allowance. This may not be the case in the current study, as there was no impact of SD on aggressive damage at older ages.

Aggressive damage is a major welfare concern in turkeys as it is painful and can lead to unnecessary culling of otherwise healthy birds (Buchwalder and Huber-Eicher, 2003). In this study, aggressive damage included any bird that demonstrated an open lesion as a result of pecking or as a result of a skin tear. Skin tears were included, as they typically attract attention of pen mates resulting in further bird damage due to pecking. Although not statistically significant, the total incidence of aggressive damage and skin tears follows the same pattern as aggression associated mortality (Chapter 2). The total incidence of aggressive damage separated by age demonstrated quadratic relationship with increasing SD in young birds (4-8 wk, highest in both 30 and 60 kg/m^2), to the author’s knowledge this has not previously been seen in young poults in relation to SD. A previous study evaluating the effects of SD on aggressive behaviour demonstrated no effects in birds as young as 6 wk of age (Martrenchar et al., 1999). In addition, previous studies have seen increases in aggression with decreases in space allowance in older birds, which was not seen in the current study (Buchwalder and Huber-Eicher, 2003). Conversely, Denbow et al. (1984) evaluated behaviour at 12 and 20 wk in relation to SD and found no effects, however they did not evaluate antagonistic behaviour in younger birds. When evaluated by the location of aggressive damage, young birds (0-4 and 4-8 wk) supported an increase in aggressive damage with increasing SD, that was seen in older birds (Buchwalder and Huber-Eicher, 2003) with more damage seen on the tail, neck, and snood. The current study also found a quadratic effect on the incidence of skin tears, with damage occurring at both extremes (30 and 60 kg/m^2). Although not necessarily a result of aggression, the increase in skin tears may be the result of increased activity at low SD (increased percentage of birds walking and decreased percentage of birds resting) as well as decreased space for birds to walk past resting birds at high SD. This may also support the decrease in back feather condition with increasing SD at older ages possibly in relation minimal bird space.

Feather cleanliness is not typically evaluated in relation to turkey SD. High SD resulted in dirtier birds, with the birds becoming dirtier over the course of the trial (wk 10, 12, and 16). Feather cleanliness is important for thermoregulation (Forkman and Keeling, 2009). As feathers come into contact with excreta from the litter, they become wet and dirty and are more likely to lose heat to the environment (Hunter et al., 1999). Feather cleanliness is also important for meat quality and safety as feathers contaminated with excreta may pose a health risk (Wilkins et al., 2003). Bird cleanliness is expected to decrease with increasing SD as there is a greater volume of excreta output with increasing SD (Dozier et al., 2005) and birds are more likely to come into contact with dirty litter. In this study, core body temperature decreased with increasing SD in turkey toms at 16 wk of age. To the best of the author’s knowledge, core body temperature has not previously been evaluated in turkey toms in relation to SD. Litter temperature has been evaluated in relation to increasing SD in broiler chickens and has demonstrated increased litter temperature with higher densities (Reiter and Bessei, 2000). While this does not support the decrease in body temperature seen with increasing SD the authors noted that there was a temperature gradient with temperatures below the litter surface being the warmest, the litter surface being intermediate and the temperature of the air between the birds being the coolest. As a result, the birds may not necessarily be exposed to the heat generated by the litter and in turn the litter may be less exposed to the air, resulting in higher litter moisture.

The H/L ratio was significantly higher with increasing SD at 4 wk of age, although no differences were seen at wk 12 or wk 16. Few studies have evaluated the H/L ratio in relation to turkey SD, however one study found no effect with increasing SD (up to 58 kg/m^2) in turkey toms from 7, 12, 16, and 20 wk of age (Hafez et al., 2015). This could suggest that either SD or group number impacts stress levels at younger ages, rather than later in life. The effect of SD on the H/L ratio of broiler chickens has also been evaluated, however there have been mixed results. Certain studies have demonstrated an increase in the H/L ratio with increasing SD (Thaxton et al., 2006; Simitzis et al., 2012) however both of these studies varied SD by changing group size, which may have been a confounding effect. The authors of the later paper also suggested that an increase in temperature during the last period of the trial may also have resulted in heat stress impacting the H/L ratio (Simitzis et al., 2012). Other research has demonstrated no effect of SD on the H/L ratio (Martrenchar et al., 1997). Martrenchar et al. (1997) noted that it was unclear if SD did not result in stress or if the H/L ratio was a poor indicator of stressors associated with SD. In the present study, the effects seen on the H/L ratio at 4 wk of age correspond to the numerical increases in aggressive damage from 0-4 wk, which then became statistically significant showing a quadratic effect from 4-8 wk with the highest incidence of damage occurring at 30 and 60 kg/m^2. In addition, mortality and culls associated with aggression increased linearly with increasing SD (Chapter 2) suggesting that the H/L ratio is likely an indicator of stress associated with increased SD and increased group size. The lack of significant differences in older birds may be attributed to habituation to increased group numbers, or perhaps attributed to different stressors becoming apparent at varying densities. Birds at low densities (30 kg/m^2) were disturbed more while resting, participated in more strutting behaviour which can be linked to sexual maturation, and exhibited a higher incidence of aggressive pecking. Birds at higher densities (60 kg/m^2) exhibited poorer gait scores, increased foot pad lesions, poorer cleanliness, as well as increases in aggressive pecking behaviour.

Behaviour is often used as a method of evaluating bird wellbeing as it relates to the bird's affective state. Birds that are feeling well and have a positive affect perform a wide array of natural behaviours, which typically include play behaviours and exploratory behaviours (Duncan, 1998). In addition, alterations in the frequency of behaviours or the presence of behaviours associated with fear and pain may be indicative of a welfare problem (Duncan, 1998). There are limited studies involving turkey behaviour in relation to increasing SD, making comparisons to previous work difficult.

Although there are few studies evaluating turkey behaviour in relation to SD, Martrenchar et al. (1999) found few differences in activity of turkeys in relation to SD. In the present study, differences in the percentage of birds resting, standing, and walking varied in relation to increasing SD. The greater space allowance at low SD may allow for more activity, as shown by the decreased percentage of birds walking with increasing SD (12, 14, and 16 wk) and decreased percentage of birds resting with increasing SD (14 and 16 wk). This increase in activity further supports the improvements in bird mobility at low SD, as poor mobility has been linked to decreased activity levels or ability to move around (Classen et al., 1994). Standing behaviour responded quadratically to increasing SD, with more birds standing at low (30 kg/m^2) and high (60 kg/m^2) SD. A previous study demonstrated that broilers stood less as a result of increased foot pad lesions (Febrer et al., 2006). This may the case for birds housed at moderate SD as footpad lesions increased linearly with increasing SD and the birds were seen resting more frequently. Since the birds housed at 50 kg/m^2 showed more birds resting, it could be suggested that birds housed at 60 kg/m^2 did not have the space to rest comfortably and more birds are seen standing as a result. In addition, the percentage of birds being disturbed showed a linear decrease with increasing SD (12 wk), which may be a result of the improvement in mobility as more birds are moving around at low SD. Broiler chicken research has shown similar results, with decreases in activity in relation to higher SD (Martrenchar et al., 1997; Hall, 2001). However, these results contradict the previous research in turkeys in which there was a tendency for more disturbances at higher housing densities (Martrenchar et al., 1999). It is important to note that the densities in the previous study were lower than the SD evaluated in the current study.

Feeding and drinking behaviours are important, especially in birds who are selected for growth. No differences in relation to SD were noted in the percentage of birds performing nutritive behaviours at 12 wk of age, however at wk 14 there was a tendency for reduced feeding behaviour with increasing SD. At 16 wk, toms were observed significantly less engaging in nutritive behaviours at higher densities and the differences were noted more so in percentage of birds present at the feeder as opposed to the drinker. These results may also coincide with the reductions in body weight seen at older ages (Chapter 2). Similar results have been shown in broiler chickens, where there was a lower probability of having a bird standing at a feeder or drinker as SD increased (Simitzis et al., 2012). Conversely, Martrenchar et al. (1999) found no differences in nutritive behaviours either as the percentage of total activity or as the duration of feeding or drinking bouts in relation to increasing SD in either turkey hens [38.8 to 62.7 kg/m^2] or toms [33.5 to 52.3 kg/m^2]. The reduction in nutritive behaviour is not a result of available feeder and drinker space, as it was allocated on a per bird basis. It is therefore likely a result of reduced mobility, social stress, or increased difficulty getting to the feeders and drinkers. This has been suggested previously by Simitzis et al. (2012). These authors noted that the birds became less active and had more difficulty walking past pen mates often bumping into each other.

Comfort behaviours have been grouped together to include stretching, wing flapping, dustbathing, head scratching, and feather ruffling. Preening was not included in this, as preening has also been associated with maintenance behaviours or displacement behaviours (Duncan and Wood-Gush, 1972; Delius, 1988). Comfort behaviours were not affected at wk 12 or 16, however at wk 14, birds at the lowest SD had a lower percentage of birds expressing these behaviours. This may be a result of the birds having additional space to exhibit other behaviours such as walking, strutting, and environmental pecking, which were numerically higher at low densities; however these are also low frequency behaviours and as a result may not show significance. Preening behaviour increased at both of the later ages (wk 14 and 16) with the highest frequency occurring at the higher densities. The increase in preening behaviour at high SD may correspond with the poorer feather cleanliness, indicating the need for an increase in feather maintenance behaviours. Conversely, the lack of significant differences at 12 wk regardless of the poor feather cleanliness scores at high SD suggest that the increase in preening at later ages may be a result of increased stress and pressure due to increasing density. Birds at later ages (heavier weights) may be experiencing greater space restraints and have limited activity, resulting in increases in preening as a displacement behaviour. The percentage of birds exhibiting aggressive pecking was significantly different at 16 wk, however birds were most aggressive at the lowest density and highest density. This could occur for two reasons, birds at low SD may be more active and as a result may participate in more posturing and fighting, while it is also possible that birds at high SD are exhibiting frustration consistent with the increase in preening.

In conclusion, high SD significantly impacts turkey tom health and welfare to 16 wk of age. It was hypothesized that high SD would result in increased competition and aggression, resulting in stress. There was no impact of SD on the H/L ratio at older ages, however other parameters measured suggest that the birds are likely experiencing stress in relation to increasing SD. It was also hypothesized that increasing SD by increasing group size, would alter group dynamics and result in space restrictions negatively impacting mobility, foot pad lesions, feather condition, and feather cleanliness. High SD (60 kg/m^2) resulted in poorer mobility, increased foot pad lesions, poor feather condition, and decreased feather cleanliness, supporting the above hypothesis. In relation to behaviour, it was hypothesized that exercise related behaviours and comfort behaviours would be the most impacted by increasing SD. This hypothesis was accepted, as it appears that both extremes of high (60 kg/m^2) and low (30 kg/m^2) SD result in behavioural changes, such as decreased activity, increased resting, and quadratic effects on aggressive pecking behaviours. Comfort behaviours were less impacted than anticipated, with minor differences seen at 14 wk of age. As a result, high SD (60 kg/m^2) negatively impacted bird health and wellbeing however, it is important to note that low SD (30 kg/m^2) was also not always the most favourable option. To achieve ideal bird health and wellbeing low to moderate densities (30 to 40 kg/m^2) may be ideal, however performance parameters should also contribute when selecting optimal SD.

3.6 Acknowledgements

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4.0 Chapter 4: Overall discussion

4.1 Introduction

Stocking density is an important management factor that can greatly impact economic return as well as bird welfare. There is large variation in the recommendations for turkey SD within North America, which may be a result of little or outdated research. The Certified Humane program recommends a maximum housing density of 36.6 kg/m^2 (Humane Farm Animal Care, 2014) whereas the National Turkey Federation (2012) recommend up to 73.2 kg/m^2. The Canadian Codes of Practice (NFACC, 2016) currently recommend housing heavy toms up to 65 kg/m^2. In addition to heavy toms, turkeys are reared to lighter weights based on the final marketed product and therefore have different SD recommendations for birds up to 13.3 kg (up to 55 kg/m^2; NFACC, 2016). It is therefore important to consider the effects that SD may have throughout the various rearing ages.

The purpose of this study was to evaluate the effects of stocking density on performance, health, and wellbeing of turkey toms reared up to 16 wk of age. Stocking density was evaluated using four graded levels of SD (30, 40, 50, and 60 kg/m^2). The effects of SD on turkey tom performance were determined using body weight, feed consumption, feed efficiency, flock uniformity, and mortality data. The effects of SD on turkey tom health and wellbeing were determined using mobility scoring, foot pad lesion scoring, feather condition and cleanliness scoring, heterophil/lymphocyte ratios, incidence of aggressive damage, as well as core body temperature. Finally, the effects of SD on turkey tom behaviour were evaluated using field of view observations at 20 minute scan sampling intervals over 24 h time periods.

4.2 Objectives

The objectives of this research were to provide a comprehensive data set to aid in the determination of stocking density recommendations for heavy turkey toms. A secondary objective was to determine the effects of stocking density on turkey toms at various ages including 4, 8, 12, and 16 wk of age. This was achieved through several smaller objectives including:

- To determine the effects of stocking density on turkey tom performance;
- To determine the effects of stocking density on turkey tom health and wellbeing;
- And finally, to determine the effects of stocking density on turkey tom behaviour.

4.3 Discussion

While the increased levels of turkey tom SD evaluated in this work (30, 40, 50, and 60 kg/m^2) result in increased income (without quantifying the increase in management costs, equipment damage, etc. that could result from increased bird numbers within a space), there are certainly consequences for the birds. These consequences are noted in both turkey tom productivity and wellbeing, but often these parameters are inter-related.

With regards to performance parameters (summarized in Table 4.1), increasing SD results in a decline in total body weight and body weight gain in the final rearing period of 12-16 wk, as well as overall (0-12 and 0-16 wk). This is important, because these ages (12 and 16 wk) are approximately those reached for specific target market body weights in Canada. Feed intake (12-16 wk) and feed efficiency (4-8, 8-12, 12-16, and overall 0-12 and 0-16 wk) are also negatively impacted by increasing SD in toms marketed at these ages. Health, behaviour, and welfare data (summarized in Table 4.2 and Table 4.3) collected in this work identify a number of causes that could contribute to this decrease in performance.

Mobility may play a key role in the decrease in performance seen as SD increases, as poor mobility may impact the bird's ability to access resources such as feed and water. Gait score was significantly poorer at higher SD (16 wk) and foot pad lesions increased with increasing SD (10 and 16 wk). These two parameters are not mutually exclusive, as decreases in mobility may be associated with pain due to foot pad lesions as seen in previous literature (Weber Wyneken et al., 2015). The impact of SD on bird performance and mobility may further be supported by the changes in behaviour. Birds at the lowest SD were most active and were seen resting less frequently than those housed at moderate SD, and as a result were more likely to access resources. This is further supported as feeding behaviour decreased with increasing SD particularly in the last week (wk 16). Birds at higher densities were seen less frequently at the feeder, which may be due to increased difficulty in maneuvering towards the feeders due to lack of space or due to the poorer mobility observed at wk 16. It should also be noted that birds at the highest SD were not seen resting the most, rather more birds were seen standing, which suggests that there may be a lack of space for birds to lie down comfortably.

Other factors that may result in decreased performance are increased stress and immune function. During the stress response, corticosterone release results in a redirection of energy (glucose) stores, whereby growth in the form of protein accretion is slowed as glucose utilization is restricted (Carsia, 2015). The body initially directs energy towards the adaptive immune response, resulting in stimulation of antibodies, stimulation of heterophil production, and reduction in lymphocyte numbers (Carsia, 2015). In the event of a chronic stressor, energy is directed towards maintaining the stress response and less energy is available for the innate immune system and growth (McFarlane et al., 1989; McFarlane and Curtis, 1989; Carsia, 2015) resulting in a greater energy expenditure and may lead to poorer feed efficiency. The early effect on feed efficiency as a result of stress is supported by the early increase in the H/L ratio (wk 4) with increasing SD. In addition the differences in infectious related mortality and culls (8-12 wk), suggest that the shift in the H/L ratio may relate to poorer immune function. This is further supported as the H/L ratio at 12 wk of age followed the same trend seen at 4 wk, suggesting that birds are still experiencing some form of stress as a result of increased SD resulting in poorer feed efficiency and lower final body weights. Other behavioural changes may be indicative of stress, which could also help explain the poorer feed efficiency throughout the study at high SD. The increased SD as a result of increasing group size may relate to higher levels of aggression at high densities, as seen by an increase in aggressive pecking behaviour in older birds (wk 16). In addition, the increase in mortality and culls due to aggression (wk 4-8) and the increase in the incidence of aggressive pecking in younger birds (wk 4-8) with increasing SD, may also contribute to higher stress levels (supported by the increased H/L ratio at this age) and poorer feed efficiency.

Stocking density can be altered through changing the space allowance per bird or through changing the group size, which could cause increased stress and competition. In commercial applications producers will change the later. In previous studies, increasing group size has been associated with increased stress levels and aggression in both laying hens and turkeys (Bilčík et al., 1998; Keeling et al., 2003; Buchwalder and Huber-Eicher, 2005). In layers, intermediate group sizes (30 birds) resulted in greater aggression whereas larger group sizes (60-120 birds) resulted in a more tolerant social system (Keeling et al., 2003); however to the author’s knowledge groups larger than 100 turkeys have not been previously evaluated.

Feather cover and feather cleanliness may also related to bird health and performance. Both feather cover and feather cleanliness became poorer as SD increased (wk 10, 12, and 16), which may have contributed to the decreases in feed efficiency over the course of the trial. The decrease in feather cleanliness could also be related to decreases in litter quality, which has been associated with increasing SD in previous studies (Proudfoot et al., 1979a; Martrenchar et al., 1999). Poorer feather condition and cleanliness may have contributed to the decreases seen in core body temperature as SD increased. As a result, more of the bird's resources may have been directed towards maintenance or thermoregulation rather than growth which have been suggested in previous literature (Leeson and Morrison, 1978; Forkman and Keeling, 2009). It is also possible that core body temperature may decrease as a result of decreases seen in activity levels, as a greater percentage of birds at high SD are seen standing/resting idle. Behavioural changes also support poorer feather condition and cleanliness with increasing levels of SD. Differences were seen in the percentage of birds preening as SD increased, with more birds preening at higher SD. While preening behaviour is often associated with either comfort behaviour or displacement behaviour, it also has a functional component for maintaining and cleaning plumage (Duncan and Wood-Gush, 1972; Delius, 1988). It could be suggested that the increase in preening behaviour could be associated with decreases in feather cleanliness seen as SD increased.

Despite the concerns of higher SD, these data also indicate that very low SD (30 kg/m^2) in enclosed spaces may be less than ideal with regards to particular variables. Aggressive pecking behaviour (wk 16) was higher at low SD, compared with moderate densities (40 and 50 kg/m^2). The percentage of birds disturbed while resting was highest at low SD compared with all other densities at 12 wk of age, and the incidence of skin tears was also higher at low SD (wk 12-16), with no skin tears seen at moderate densities. All of these factors could potentially relate to the levels of increased activity that were seen with turkeys housed at low SD. Birds that are more active may be more likely to be involved in aggressive encounters or injure other pen mates. As a result very low housing densities, while suitable for performance, may not always favour bird health and wellbeing.

4.4 Conclusions

Stocking density negatively impacted performance resulting in decreased body weight and poorer feed efficiency, with birds performing best at low SD (30 kg/m^2). Many of the health parameters including mobility, foot pad lesion scores, feather condition, and feather cleanliness were negatively impacted by increasing SD with the greatest impact at 60 kg/m^2. In addition, behavioural changes suggested that both the low density and high density (30 and 60 kg/m^2) posed some concerns for bird wellbeing. Toms at the lowest density were most active, however they also showed lower levels of comfort behaviours, increased disturbance while resting, and increased aggressive pecking. Toms at the highest density showed higher levels of preening and comfort behaviours. They also demonstrated decreased levels of walking and resting, increased levels of aggressive pecking, and had a higher percentage of birds standing likely as a result of space restriction.

In conclusion, the data outlined in this thesis demonstrate that turkey tom productivity, health, and behaviour are all impacted by increasing SD. These data suggest that SD may elicit certain negative effects on birds at both extremely low density (30 kg/m^2) and extremely high density (60 kg/m^2). When numerically ranked (Table 4.4), low to moderate densities (30-40 kg/m^2) may be most suitable for 16 wk old toms as they allow for optimal performance as compared to high densities while ensuring bird health and wellbeing are not compromised. These data also illustrate that age of the birds is important to consider when selecting SD for commercial settings. In addition, turkey toms and hens likely react differently to various densities due to size and behavioural differences and as a result SD should be further assessed for its impact on turkey hen performance, health, and welfare.

Table 4.1. Summary of the effects of estimated final stocking density on turkey tom performance from 0-4, 4-8, 8-12, and 12-16 weeks of age

Parameter	0-4 (4 wk)	4-8 (8 wk)	8-12 (12 wk)	12-16 (16 wk)
Body weight	No effect	No effect	Quadratic 60 kg/m^2 lightest	Linear decrease as SD increases
Feed consumption	No effect	Linear increase as SD increases	No effect	Linear decrease as SD increases
Feed-to-gain (mortality corrected)	No effect	Linear increase as SD increases	Linear increase as SD increases	Linear increase as SD increases
Uniformity	-	-	No effect	No effect
Mortality	No effect	Linear increase as SD increases (aggression)	Linear increase as SD increases (infectious)	No effect

Table 4.2. Summary of the effects of estimated final stocking density on turkey tom health and physical condition up to 16 weeks of age

Parameter	(0-4) 4 wk	(4-8) 8 wk	10 wk	(8-12) 12 wk	(12-16) 16 wk
Mobility	-	-	-	No effect	Linear decrease as SD increases
Foot pad lesions	-	-	Linear increase in severity and frequency as SD increases	No effect	Linear increase in severity as SD increases
Feather condition	-	-	Linear decrease as SD increases	Linear decrease as SD increases	Linear decrease as SD increases
Feather cleanliness	-	-	Linear decrease as SD increases	Linear decrease as SD increases	Linear decrease as SD increases
Aggressive damage	Quadratic effect (tail) 60 kg/m^2 greatest	Linear increase (neck), quadratic effect (snood) 60 kg/m^2 greatest	-	No effect	Quadratic effect (skin tears) 60 kg/m^2 greatest
Heterophil/lymphocyte ratio	Linear increase as SD increases	-	-	No effect	No effect
Core body temperature	-	-	-	-	Linear decrease as SD increases

Table 4.3. Summary of the effects of estimated final stocking density on turkey tom behaviour at 12, 14, and 16 weeks of age

Behaviour	12 wk	14 wk	16 wk
Resting	No effect	Linear increase as SD increases	Quadratic effect, greatest at 50 kg/m^2
Standing	Quadratic effect, greatest at 60 kg/m^2	No effect	Quadratic effect, greatest at 60 kg/m^2
Walking	Linear decrease as SD increases	Linear decrease as SD increases	Quadratic effect, greatest at 30 kg/m^2
Feeding	No effect	No effect	Quadratic effect, greatest at 30 kg/m^2
Drinking	No effect	No effect	Quadratic effect, greatest at 30 kg/m^2
Preening	No effect	Linear increase as SD increases	Linear increase as SD increases
Comfort	No effect	Linear increase as SD increases	No effect
Strutting	No effect	Quadratic effect, greatest at 30 kg/m^2	No effect
Aggressive pecking	No effect	No effect	Linear effect, greatest at 60 kg/m^2
Total disturbance	Linear decrease as SD increases	No effect	No effect

Table 4.4. The effects of estimated final stocking density on turkey tom performance, health, and behaviour at 16 weeks of age, with ranking (1-4) with 1 representing best and 4 representing poor

Parameter	Estimated final stocking density (kg/m^2)			
	30	40	50	60
Performance				
Body weight	1	2	3	4
Feed-to-gain (mortality corrected)	1	1	3	4
Uniformity*	-	-	-	-
Mortality*	-	-	-	-
Economics	4	3	2	1
Average performance rank	**2.0**	**2.0**	**2.7**	**3.0**
Final performance rank	**1**	**1**	**3**	**4**
Health and physical condition				
Gait score (mobility)	1	3	2	4
Footpad lesion score	2	1	3	4
Feather condition score	1	2	3	4
Feather cleanliness score	1	2	3	4
Heterophil/lymphocyte ratio*	-	-	-	-
Incidence of skin tears	3	1	1	4
Behaviour				
Walking	1	2	4	3
Feeding	1	2	4	3
Aggressive pecking	3	1	2	4
Average health/physical condition and behaviour rank	**1.63**	**1.75**	**2.75**	**3.75**
Final health/physical condition and behaviour rank	**1**	**2**	**3**	**4**

*Data not statistically significant, therefore not included in ranking.

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6.0 Appendices

Table 6.1. Effect of estimated final stocking density on turkey tom body temperature by time period at 16 weeks of age

Time	Estimated final stocking density (kg/m^2)				SEM[1]	P-value	P-value	Regression Equation[2]
	30	40	50	60		(Linear)	(Quadratic)	
Breast transponder								
4:00AM	37.85	37.60	37.20	37.85	0.260	0.87	0.41	-
5:00AM	37.70	38.53	37.63	37.50	0.220	0.46	0.29	-
6:00AM	38.18	37.93	38.37	37.58	0.210	0.48	0.54	-
7:00AM	37.80	38.31	38.48	37.52	0.217	0.73	0.09	-
8:00AM	38.33	38.20	38.05	37.88	0.210	0.44	0.97	-
9:00AM	37.95	38.67	37.45	37.63	0.278	0.40	0.64	-
10:00AM	38.30	38.50	38.68	37.55	0.215	0.29	0.12	-
11:00AM	38.38	38.32	37.88	38.25	0.259	0.73	0.69	-
12:00PM	38.25	38.50	38.75	38.08	0.188	0.89	0.24	-
Wing transponder								
4:00AM	39.62	39.66	38.80	39.02	0.139	0.03	0.67	Y=-0.03x+40.44
5:00AM	39.78	39.58	39.43	39.15	0.210	0.23	0.92	-
6:00AM	40.07	39.60	39.03	38.93	0.158	<0.01	0.47	Y=-0.04x+41.19
7:00AM	39.62	39.14	38.95	38.80	0.189	0.11	0.67	-
8:00AM	39.98	39.70	38.88	38.87	0.173	<0.01	0.61	Y=-0.04x+41.22
9:00AM	39.78	39.64	39.10	39.20	0.153	0.09	0.65	-
10:00AM	40.25	39.74	39.25	39.15	0.182	0.01	0.53	Y=-0.04x+41.31
11:00AM	40.10	39.78	39.12	39.30	0.168	0.04	0.40	Y=-0.03x+40.95
12:00PM	39.97	39.94	39.35	39.35	0.121	0.02	0.90	Y=-0.02x+40.73
iButton								
4:00AM	40.99	40.75	40.95	40.26	0.136	0.15	0.44	-
5:00AM	41.37	41.00	41.32	41.26	0.073	0.96	0.31	-
6:00AM	41.49	41.00	40.82	41.09	0.170	0.34	0.28	-
7:00AM	41.12	41.25	41.07	40.42	0.129	0.08	0.11	-
8:00AM	40.74	41.25	40.82	40.92	0.117	0.91	0.41	-
9:00AM	41.12	41.25	41.20	40.92	0.088	0.52	0.29	-
10:00AM	41.12	41.37	41.20	40.92	0.096	0.48	0.19	-
11:00AM	41.12	40.62	40.82	40.92	0.187	0.79	0.45	-
12:00PM	40.99	41.24	40.82	40.92	0.113	0.55	0.73	-

[1]Standard error of the mean.
[2]Regression considered significant if $P \leq 0.05$.

Presentations

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